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Restoration of Lower St. Regis Lake Franklin County, New York

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Lower St. Regis Lake, the lowest of a chain of three lakes in Franklin County, Adirondack Region, New York, was subject to severe eutrophication, as indicated by summer-long intense blue-green algal blooms caused by phosphate discharges from a point-source contributing approximately 0.8 g P/(sq m x yr). Sewage from the point-source had been subject to an extended aeration-activated sludge treatment. Ferric chloride was added and ferric phosphate sludge was removed from the basin from July to December 1972, from March to November 1973, and in April 1974. In May 1974 year-round diversion of the effluent to a sand bed 250 meters from the lake was begun. During the summers of 1973 and 1974 there was washout of phosphate from the lake system, and the summer bloom was delayed. In 1975 the usual spring bloom of flagellates and diatoms did not occur, and the summer bloom was further reduced in duration and intensity. The recovery of the lake is thus very much in evidence. The high iron content of the lake, among several other factors, appears to be speeding the recovery; a delaying influence is being exerted by the continued hypolimnic oxygen depletion, however, presumably from methane formed in the sediments.

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RESTORATION OF LOWER ST. REGIS LAKE
(FRANKLIN COUNTY, NEW YORK)

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report describes the recovery of a eutrophic lake in the Adirondack region of New York through point-source phosphorus control.

A.F. Bartsch
Director, CERL

ABSTRACT

Lower St. Regis Lake, the lowest of a chain of three lakes in Franklin County, Adirondack Region, New York, was subject to severe eutrophication, as indicated by summer-long intense blue-green algal blooms caused by phosphate discharges from a point source contributing approximately 0.8 g P/(sq m x yr). The upper lakes are only mildly eutrophic, possibly as the result of lakeshore cottage development. The remainder of the basin is forested. Sewage from the point source had been subject to an extended aeration-activated sludge treatment. Ferric chloride was added and ferric phosphate sludge was removed from the basin from July to December 1972, from March to November 1973, and in April 1974. In May 1974 year-round diversion of the effluent to a sand bed 250 meters from the lake was begun. During the summers of 1973 and 1974 there was washout of phosphate from the lake system, and the summer bloom was delayed. In 1975 the usual spring bloom of flagellates and diatoms did not occur, and the summer bloom was further reduced in duration and intensity. The recovery of the lake is thus very much in evidence. The high iron content of the lake, among several other factors, appears to be speeding the recovery; a delaying influence, however, is being exerted by the continued hypolimnic oxygen depletion, presumably from methane formed in the sediments.

This report was submitted in fulfillment of EPA grant S-801529 administered through Health Research, Inc., a research organization in the New York State Department of Health. This report covers a period from May 9, 1972 through October 31, 1975, when field surveys were completed.

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LIST OF ABBREVIATIONS AND SYMBOLS

UNIT OF MEASURE	
a-ft	acre-foot
°C	degree Celsius
cap^{-1}	per capita (per person)
cfs	cubic foot per second
cm	centimeter
ft	foot
g	gram
g liter^{-1}	gram per liter
gpd	gallon per day
in	inch
km	kilometer
km^2	square kilometer
L sec^{-1}	liter per second
m	meter
m^2	square meter
m^3	cubic meter
m^3 day^{-1}	cubic meter per day
m^3 sec^{-1}	cubic meter per second
meq liter^{-1}	milliequivalent per liter
mg liter^{-1}	milligram per liter
mi	mile
mi^2	square mile
ml	milliliter
mm	millimeter
mm^3 liter^{-1}	cubic millimeter per liter
N	normal
nm	nanometer
ppm	parts per million
rpm	revolutions per minute
yr	year
µ	micron
µg day^{-1}	microgram per day
µg liter^{-1}	microgram per liter
µg-at liter^{-1}	microgram-atom per liter
µS cm^{-1}	microSiemens per centimeter

CHEMICAL SYMBOL	
C org. sol.	organic soluble carbon
Ca^{2+}	calcium ion
Ca total	total calcium
Cl^-	chloride ion
CO_2	carbon dioxide
COD	chemical oxygen demand
EDTA	ethylenediamine tetra-acetic acid
Fe total	total iron
HCl	hydrochloric acid
K^+	potassium ion
Mg^{2+}	magnesium ion
$MgCO_3$	magnesium carbonate
Mn total	total manganese
N organic	organic nitrogen
Na^+	sodium ion
NaOH	sodium hydroxide
$N(NH_4)$	ammonia nitrogen
$N(NO_3 + NO_2)$	nitrate and nitrite nitrogen
P	phosphorus
P react.	reactive phosphorus
P total part.	total particulate phosphorus
P total sol.	total soluble phosphorus
Si react.	reactive silica
$SO_4{}^{2-}$	sulfate radical
TKN	total Kjeldahl nitrogen

OTHER

A	interlake flow
Bl	Black Pond outlet
C_1	lake level constant = 73.1 m^3 sec^{-1}
C_2	precipitation constant = 0.731 m^3 sec^{-1}
C_3	evaporation constant = 0.512 m^3 sec^{-1}
E	evaporation
Ea	Easy Street Creek
L	lake level
$\bar{L}$	lake level from previous day
L_p	areal phosphorus loading
$[P]^{sp}$	predicted phosphorus concentration at spring overturn
Pr	precipitation
q_s	hydraulic loading
SD	standard deviation
St	St. Regis River flow
t	actual temperature
USGS	United States Geological Survey
X	total runoff from ungaged areas
Z	runoff from the upper basin
$\bar{z}$	mean depth
τ_w	mean hydraulic retention time

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Of the two principal investigators, Dr. Leo J. Hetling of the New York State Department of Environmental Conservation was responsible for the hydrologic and sanitary engineering aspects, while the senior author of this report supervised the limnological study and the telemetering project. Significant contributions to this report were made by Dr. Thomas F. Zimmie of Rensselaer Polytechnic Institute (water balance), Salvatore D. Schiavo and staff of the Albany office of the U. S. Geological Survey (stream gage calibration), Robert J. Dineen of the New York State Geological Survey (geology), and the following employees of the Environmental Health Center: Dr. Douglas Mitchell and staff (chemical analysis), Dr. Michael M. Reddy (sediment core and detritus analysis), Dr. Lindsay W. Wood (phosphate dynamics in sediment cores), Miss Susan P. Allen (plankton analysis) and Mr. Thomas B. Lyons III (data processing).

Capable technical assistance was rendered by Messrs. William C. Ahearn, Thomas B. Lyons III, and Eugene Schmidt of the Environmental Health Center and by Mr. John Bouton, who was employed under contract with Paul Smith's College.

A concurrent student project on lake analysis was initiated and conducted at Paul Smith's College by Mrs. Patricia Flath, instructor in chemistry.

Additional credits are given in the report by Dr. T. James Tofflemire (1975) for participants in the engineering aspects of the study.

Mr. Richard McCormick, District Engineer for the New York State Department of Health, has been of great help to all participants in the study on many occasions.

SECTION 1

INTRODUCTION AND RATIONALE

This study was prompted by complaints in August 1970 from the St. Regis Property Owners Association, Inc., about apparent degradation of the lowest in the St. Regis chain of lakes, located approximately 16 kilometers (km) (10 miles [mi]) northwest of the Village of Saranac Lake in Franklin County, Adirondack Region, New York. Intense algal blooms were noticed each summer, in contrast to the lack of blooms on the two upper lakes. The association represents owners of summer homes around the two upper lakes, and the allegations focused on the discharge of treated wastewater into the lower lake by Paul Smith's College, the only significant development on the lower lake.

The complaints were voiced to the New York State Department of Environmental Conservation, which on July 1, 1970 had assumed water pollution control responsibilities from the Department of Health, although the latter retained jurisdiction for potable and recreational water quality. Upon first reconnaissance the algal problem was obvious, and we were informed that the problem was of long standing. In contrast to the upper lakes - which, despite the absence of public beaches and with only a marginal public launching facility, had much recreational use, including sport fishery - the lower lake seemed little used. The main complaint was the unsatisfactory aesthetic quality of the water, and it seemed possible that if the lower lake were restored to a better water quality, it would be utilized to a greater extent.

Water pollution control measures on the lower lake were not significantly behind the state of the art. During the intense recreational use of this lake in connection with Paul Smith's Hotel on its shores (1859-1930), septic tank service had been sufficient. When Paul Smith's College (established 1946) grew near its present size, sanitary conditions required the construction of a secondary sewage treatment plant (1965-67), which proved to be ample in size and well functioning. When algal problems continued, the State Health Department recommended pumping the effluent to sand beds rather than discharging it to the lake (1971). This system was under design when the present study began.

Following receipt of the residents' complaints, the Environmental Health Center of the Division of Laboratories and Research, New York State Department of Health, in cooperation with the Department's Saranac Lake District Office and the Environmental Quality Research Unit of the New York State Department of Environmental Conservation, conducted a one-time survey (1971) of the lake system and assembled information pointing to possibility of eutrophication caused by the significant phosphate discharges from the college treatment plant. This survey also determined that phosphate was the limiting nutrient in the dense population of potentially nitrogen-fixing blue-green algae. In 1972 the U. S. Environmental Protection Agency expressed interest in projects which could clearly, and within a short period of time, show whether phosphate was a key element in eutrophication and whether eutrophication in lakes could be checked by point-source phosphorus control. Lower St. Regis Lake was found to be well suited for such a study. There were two main reasons: (1) from all that could be ascertained, phosphate discharges from a single source seemed to cause the degradation of the lake. The evidence at that time was indirect: the better quality of the upper lakes, which did not have similarly sized discharges; (2) the existing sewage treatment plant could immediately be converted to include the chemical precipitation of phosphates, while the effectiveness of land disposal (groundwater recharge) could be studied in subsequent years.

These advantages were considered more significant than the obvious disadvantage that the basin was ungaged, so that it was virtually impossible to assess natural hydraulic and nutrient inputs with great accuracy - a disadvantage that would make judgment of the success of restoration efforts dependent on a comparison of the lower lake with the upper lakes. For these and the other reasons, the project was designed primarily as a demonstration of practical results that can be obtained with phosphate point-source control, rather than as an intensive limnological research study.

Three additional goals were also set and achieved: (1) to gain experience in the chemical precipitation of phosphate in a small biological treatment plant, seasonally and under severe winter conditions; (2) to assess the phosphate-absorptive capacity of sandy soil of low alkali content; and (3) to gain experience with low-cost telemetering systems for the collection of physical and physiochemical data in remote areas and under severe climatic conditions.

Investigations under goals 1 and 2 are described in a separate report by T. J. Tofflemire (1975). The telemetering system was described in specifications submitted separately to the U. S. Environmental Protection Agency (Kachemov et al., 1973) and has been implemented and tested with several modifications, most recently in a version for stream and lake level gaging involving four remote stations and one printing master station.

RATIONALE

The decision to attempt restoration of Lower St. Regis Lake by point-source phosphorus control was based on the apparent effect of the point source, which contributed an estimated loading of

$$\frac{1.2 \times 10^3 \text{ g P} \cdot \text{yr}^{-1} \cdot \text{cap}^{-1} \times 1000 \text{ people}}{145.7 \times 10^4 \text{ m}^2} = 0.82 \text{ g P} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$$

where g = gram
P = phosphorus
yr = year
cap^{-1} = per capita (per person)
m^2 = square meter

prior to the State's ban on phosphate detergents (July 1972) and about half that amount after the ban was in effect. Phosphorus was established as the critical nutrient in bioassay experiments.

The circumstances permitted immediate seasonal chemical removal of 80-85% of sewage phosphorus by chemical precipitation. This could later be converted to year-round removal of a presumably larger fraction by groundwater recharge under soil and topographic conditions which could be judged as effective as those of Lake George Village, Warren County, New York (Fuhs, 1972; Aulenbach et al., 1975), where a similar system has been in operation for over 35 years.

Ferric chloride rather than alum was selected as a precipitant for phosphate (for details see Tofflemire, 1975) in order to avoid the possible stimulation of microbial sulfate reduction in the lake by sulfate additions. In many freshwater environments rich in organic matter, sulfate is the limiting element for this process, which causes formation of hydrogen sulfide and the operation of a sulfur cycle with its various undesirable aspects. In the case of Lower St. Regis Lake it was particularly important to retain the substantial amounts of iron which cycle between the hypolimnion and the sediments for the precipitation of phosphates in situ. Addition of sulfates to the unstabilized sediment in the presence of iron would have resulted in the preferential formation of hydrated ferrous sulfides and a corresponding loss of phosphate-binding capacity.

SECTION 2

CONCLUSIONS

Point-source phosphorus control has proved to be an effective means of reducing eutrophication in Lower St. Regis Lake. Eliminating summer inputs of sewage phosphates would have resulted in a gradual improvement of the lake, but year-round diversion of sewage effluent to sand beds resulted in more extensive and more rapid recovery. The latter method is probably easier to practice in small installations and with an adverse winter climate. Recovery was aided by both the morphometry and the chemistry of the lake and its basin. This treatment method permits the acid-binding capacity (alkalinity) of the wastewater to reach the lake, counteracting in a desirable manner the natural acidity and thereby tending to reduce productivity.

Details of the engineering aspects have been reported by Tofflemire (1975).

SECTION 3

RECOMMENDATIONS

Phosphate should be the target for eutrophication control in freshwater lakes wherever (a) phosphate is the limiting element or (b) nitrogen is limiting, but nitrogen-fixing algae are present or may become established.

The effectiveness of phosphorus removal on eutrophication reduction depends on the total reduction of the phosphorus loading, modified by factors such as the availability to algae of phosphorus from natural sources; basin morphology and stratification; seasonal patterns of input and lake flushing; and lake chemistry, particularly the availability of phosphate-binding cations. The speed of recovery depends on these same factors and also on the oxygen demand and nutrient content of the sediments, particularly on the sulfur cycle and the carbon dioxide-methane cycle.

Phosphate removal can be practiced by addition of iron or alum and subsequent removal of mineral phosphate sludge at a secondary (biological) treatment plant. Alum or other sulfates should not be chosen when sulfate additions may promote sulfate reduction and thereby reduce the iron-binding capacity of the sediments. Ferric chloride, however, is corrosive, and its handling is difficult at low temperatures (Tofflemire, 1975).

Complete diversion of secondary effluent to natural sand beds several hundred meters or more from the lake can be convenient and effective for virtually complete long-term removal of phosphate, while soluble elements and most of the nitrogen will pass through. The sand beds should be tested thoroughly with regard to their hydraulic and chemical properties, but the phosphate-retaining capability even of sands that are quite low in alkaline constituents can be adequate.

This solution is particularly convenient where a very high degree of phosphate removal must be attained. The method is not restricted to the treatment of wastes from conventionally sewered areas. It can be adopted to lakeshore developments using the less-expensive pressure-sewer systems or any other means of collection and treatment.

The indicated methods of phosphate removal, particularly groundwater recharge, permit the alkalinity (acid-binding capacity) of the wastewater to reach the lake. In lakes with high natural acidity this may have a beneficial effect on the metabolism of the lake as a whole - a significant advantage of treatment for phosphate removal, as opposed to complete diversion of the sewage.

SECTION 4

LAND USE IN THE ST. REGIS LAKES BASIN AND THE HISTORY OF THE PAUL SMITHS SETTLEMENT

The Lower St. Regis Lake watershed is sparsely populated, except for the hamlet of Paul Smiths. There is very little economic activity in the area, except for Paul Smith's College, which has a population of about 1,000 during the academic year, and a small amount of lumbering and agriculture, the latter estimated as less than 5 percent of the watershed. The area is well suited for recreational activities such as hunting, fishing, hiking, and boating. Two ponds in the basin, Long Pond and Beach Pond, are special-regulation trout ponds, containing trophy trout.

The lake shorelines are densely wooded with white pine, several birch species, spruce, larch, and shrubs.

The shores of Upper St. Regis Lake and, to a lesser extent, of Spitfire Lake (which flow into Lower St. Regis Lake) are populated with summer homes, mostly owned by people in the upper income brackets. This summer population may amount to 500 people in an estimated 165 homes on the upper lake and approximately 60 on Spitfire Lake. The year-round population of these two lakes is estimated at less than 100.

With the exception of the student enrollment, the Paul Smiths settlement, including the "suburbs" of Easy Street and Otisville has a year-round population of approximately 800. Some of their dwellings have septic tanks which lead into Easy Street Creek. Five isolated cottages for temporary occupancy on Lower St. Regis Lake have septic tanks more than 30 meters (100 feet) from shore.

The Paul Smiths settlement dates back to the founding of a hotel on the shore of the lake in 1859 by Apollos (Paul) Smith, whose name the settlement now bears. The hotel developed into a flourishing resort as indicated by the growing summer population. (The resort was closed during the winter, presumably from October through May.) Table 1 reflects the guests and resort staff, including guides, as estimated from information in an article by Leslie (1965-1966) and the Paul Smith's College catalog (1974-1975). There also was an extensive horse stable.

Table 1. SUMMER POPULATION OF PAUL SMITHS SETTLEMENT

Years	Population
1859 - 1869	25
1870 - 1879	211
1880 - 1901	241
1902 - 1929	632

In 1930 the hotel burned down, and population in the settlement dwindled to approximately 30 until 1946, when, according to the will of Paul Smith's son, a college for forestry and hotel management was established in memory of Paul Smith. Since then the population of students has risen steadily (Table 2).

Table 2. STUDENT POPULATION OF PAUL SMITH'S COLLEGE

Years		
Summer - Spring	Summer	Academic year
1946 - 1950	31	170
1950 - 1955	46	153
1955 - 1960	101	319
1960 - 1965	137	546
1965 - 1970	156	616
1970 - 1975	201	664
1975	242	

SECTION 5

PREVIOUS AND PRELIMINARY STUDIES AND POLLUTION ABATEMENT MEASURES

The effects of population on Lower St. Regis Lake may have been felt at all times. The 1930 Biological Survey of the St. Lawrence Watershed by the New York State Conservation Department (1931) contains reports on aquatic weeds, plankton, and the chemistry of the St. Regis Lakes in contributions by W. C. Muenscher (p. 121-143, 145-155) and H. M. Faigenbaum (p. 167-177). Muenscher noted Secchi disc readings (a measure of water transparency) of 1.7 meters (m) in June and July and 2.0 m in August in Lower St. Regis Lake, while Upper St. Regis Lake showed a transparency of 2.4, 2.5, and 2.3 m for those months. He noted that these values on both lakes were not unusual in that area. The plankton count (cells per milliliter [ml]) was in the range of 100-300 blue-green algae, 100 green algae, 300-800 diatoms, and 100-300 protozoa in the 0-5-m layer of Lower St. Regis Lake. Algae counts in Upper St. Regis Lake were similar. Water blooms consisting of *Anabaena* and *Microcystis* were noted in the St. Regis Lakes in August.

Unfortunately the survey did not procure oxygen data on the St. Regis Lakes and is not very specific with regard to fish populations in the lower lake.

Algal blooms in Lower St. Regis Lake were definitely noted by local residents in August in the years around 1955. These blooms reportedly disappeared after Labor Day. Since 1963 the blooms have appeared earlier and, since 1968, been more persistent. Flick and Webster (1964) mentioned a heavy bloom in 1964, which they believed was caused primarily by pollution from Paul Smith's College and magnified by low water. The turbidity from algae was so great as to discourage fishing.

According to the State Health Department District Office at Saranac Lake, the reason for installing sewerage at the college campus in 1967 was an increasing problem with overflow of the subsurface disposal system (leach fields, tile beds) as population increased. Flick and Webster (1964), however, voiced hope that construction of a sewage treatment plant also might alleviate the algal bloom problem. A later report (Flick and Webster, 1965) mentioned construction of a dam at the outlet of the lake to replace a log jam swept out by high waters in 1964 and listed *Anabaena*, 18 genera of green algae, 7 genera of diatoms, and 16 genera of zooplankton in the lake effluent. In 1968 Flick and Webster described a particularly heavy summer bloom that caused the St. Regis River to look like "pea soup" for a distance of over 32 km (20 mi) downstream from Lower St. Regis Lake. Nutrients from the sewage treatment plant outfall were incriminated, and total phosphorus values of 83 and 144 micrograms per liter (μg liter^{-1}) in the lower lake, as opposed to 22 in Spitfire Lake immediately above, (all at 1.5-m depth) were cited as proof. Secchi disc values were 0.45 m in the lower lake and 3.6 m in Spitfire Lake. A meeting with local officials to discuss the problem and the possible threat of fish kills was scheduled for March 1969.

Dr. Carl Schofield of the Department of Natural Resources, Cornell University, in a letter dated August 7, 1968, to Mr. William A. Flick of Cornell's Brandon Park Fishery Laboratory, suggested that the soils in the area have a "tremendous capacity for phosphate retention" and that, according to Cooper (1967, published 1969), "forest fertilization" was a possible means of removing phosphate from treated sewage. It may well be that the planning toward land disposal was based on Schofield's suggestion. Schofield also presented chemical data such as the following: on August 25, 1967, at 1.5-m depth, total phosphate-phosphorus (μg liter^{-1}) was 11.8 in Upper St. Regis Lake, 36.3 in Lower St. Regis Lake, and 18.7 in the St. Regis River 11 km (7 mi) below the college. Sediment chemical data which Schofield obtained are discussed elsewhere in this report (p. 55).

During a preliminary survey of Lower St. Regis Lake in October 1970 (Allen, 1970) reactive phosphorus was 16 μg liter^{-1} in Easy Street Creek above the Paul Smith's College effluent entry, 10,000 in the effluent itself, 8.3-15 in Lower St. Regis Lake, and 5.6 in Spitfire Lake. Total soluble phosphorus was 19 μg liter^{-1} in Easy Street Creek, 11,000 in the effluent, 15-16 in the lower lake, and 5.6 in Spitfire Lake. Total particulate phosphorus was 1.2 μg liter^{-1} in Easy Street Creek, 1,400 in the effluent, 5.0-5.7 in the lower lake, and 5.7 in Spitfire Lake.

A one-day intensive survey of the St. Regis Lakes was conducted by the present authors on August 5, 1971 (New York State Dept. of Health, 1972). The bloom was readily apparent in the lower lake. Secchi disc transparency was 0.7 m in the lower lake and 3.2 m in Spitfire Lake. Hypolimnic oxygen depletion was noticeable in Upper St. Regis Lake (1.0 milligram per liter [mg liter^{-1}]at 19.5 m), and the lower lake had no oxygen in its hypolimnion (thermocline at 5 m). A considerable concentration of reduced iron (130 microgram-atoms per liter [μg-at liter^{-1}]) was found in the hypolimnion. During a special study in the same year, a carbon dioxide (CO_2) stripping device with a CO_2-specific infrared analyzer was used to study the gradient of productivity between Spitfire and Lower St. Regis lakes. Over a distance of 200 m in the channel between the lakes the transparency changed from a fairly clear brown to thick green, with a significant drop of CO_2 partial pressure from supersaturation to a marked undersaturation and with an increase in pH from 6.2 to 9.5 (sunny afternoon). Bioassay results (Table 3) following the method outlined in Fuhs et al. (1972) using natural plankton showed phosphate as the only limiting nutrient in spite of severe nitrogen depletion of the water. The depletion reflected the nitrogen-fixing ability of the predominant alga Anabaena. Carbon to phosphorus atomic ratios in the epilimnic plankton were as high as 488, indicating luxury carbon assimilation in phosphate limitation (Fuhs et al., 1972). The elementary composition of the sediments was also determined (for results see p.58).

In an unusual coincidence, Flick took aerial photographs of Lower

Table 3. BIOASSAYS OF LOWER ST. REGIS LAKE, 1971

	June[a]	August[b]
Control -- no additions (mg $liter^{-1}$ COD[c])	12.8	41.58
Growth with additions (ratio of sample COD[c] to control COD[c])		
Phosphorus	7.72	4.74
Nitrogen	1.68	1.09
Iron - EDTA[c] chelate	1.03	1.23
EDTA[c] chelate (control)	1.30	1.34
Trace metal mix	1.04	0.66
Vitamin mix	1.14	0.82
Sodium	1.03	0.93
Phosphorus and nitrogen	8.14	3.38
Silicon	1.38	0.95

[a] Sample collected 6/18/71. Incubation commenced on same day. COD tests done 7/19/71.

[b] Sample collected 8/5/71. Incubation commenced 8/6/71. COD tests done 9/2/71.

[c] COD and EDTA definitions: see List of Abbreviations and Symbols (p. ix).

St. Regis Lake on August 6, 1971 at 2:00 P.M., one day after our survey. The photographs reproduced here show the algal bloom condition and the sharp transition in water color in the channel from Spitfire Lake (Fig. 1). Photographs taken five years later on August 3, 1976 (Fig. 2) show that the water color of Lower St. Regis Lake now closely resembles that of the upper lake.

There are no public beaches on Lower St. Regis Lake, and bacteriologic data as a measure of direct pollution are therefore not available.

There is no apparent problem with aquatic weed growth, as pollution has primarily resulted in the development of planktonic algae. The heavy weed growths are restricted to the narrow, shallow channels of the inlet (from Spitfire Lake) and the outlet (St. Regis River) and do not seem to have changed in extent since the 1930 Biological Survey.

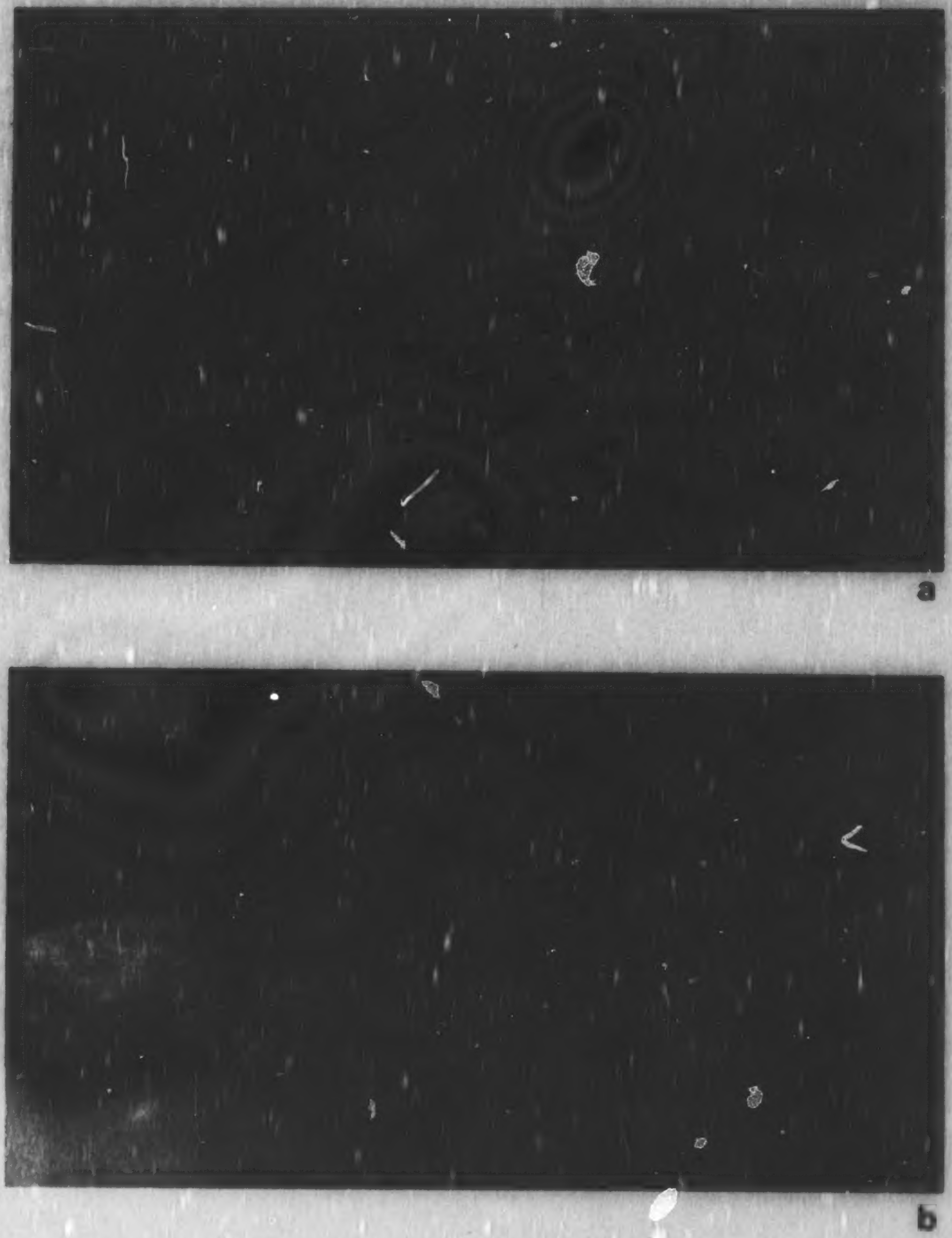


Fig. 1 (a) General view of Lower St. Regis Lake, August 6, 1971.
(b) Close-up of The Slough (channel from Spitfire Lake, upper right) entering Lower St. Regis Lake, August 6, 1971. Note the color difference of the two bodies of water. Aerial photograph, green separation from Kodak Kodachrome slide. Photography credit: Wm. Flick.

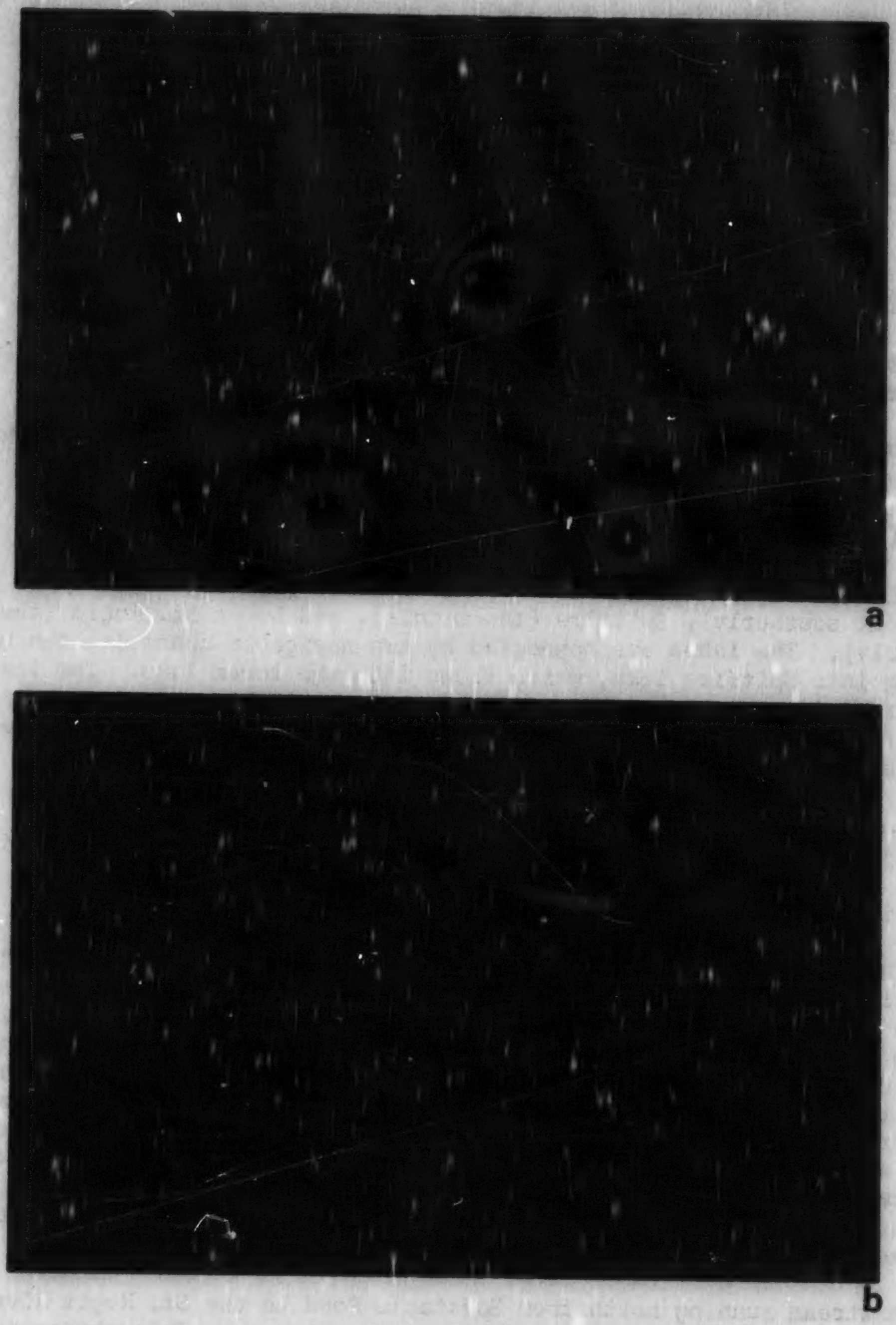


Fig. 2 (a) General view of Lower St. Regis Lake, August 3, 1976.
(b) Close-up of The Slough (channel from Spitfire Lake, upper right) entering Lower St. Regis Lake, August 3, 1976. Note the color similarity of the two bodies of water. Aerial photograph, black and white print from Kodak Vericolor II negative. Photography credit: John Goerg, NYS Department of Environmental Conservation.

SECTION 6

HYDROLOGY OF LOWER ST. REGIS LAKE

GENERAL

Please refer to Figs. 3 and 4 for hydrographic information and Table 4 for morphometric characteristics.

The entire Lower St. Regis Lake basin lies in Franklin County, New York, in the towns of Brighton, Santa Clara, and Harrietstown. The lowest elevation is that of the lake, 494 m (1,619 feet [ft]); the highest is St. Regis Mountain, 876 m (2,873 ft).

The St. Regis Lakes consist of three lakes (see Fig. 5): Upper St. Regis (the most southerly), Spitfire (the middle), and Lower St. Regis (the most northerly). The lakes are connected by two navigable channels, the upper lake flowing into Spitfire Lake, which flows into the lower lake. The lower lake discharges in a westerly direction. The St. Regis River begins at the outlet of the lower lake and flows northerly to the St. Lawrence River. The St. Regis Lakes basin is thus a subbasin of the St. Lawrence River Basin.

In addition to the three lakes, there are numerous ponds in the basin. The major ones are Black, Long, and Barnum ponds in the northern part of the basin; the two Spectacle Ponds in the western part; and Bear, Little Long, and Roiley ponds in the southern part.

The major perennial streams entering the lakes are Black Pond stream (actually unnamed), which carries the discharge from Black and Long ponds and enters Lower St. Regis Lake near the outlet to the St. Regis River; Barnum Pond stream (also unnamed), which carries the flow from Barnum Pond into the lower lake; Easy Street Creek, which enters the lower lake; two unnamed streams which enter the southern side of the upper lake; and the first of two unnamed creeks (referred to in this study as Spitfire Creek No. 1 or simply Spitfire Creek), which enters the east side of the connecting channel between Spitfire Lake and the lower lake. In addition, some intermittent streams exist in the basin, but they are not shown on United States Geological Survey (USGS) topographical quadrangle maps.

A stream running north from Spectacle Pond to the St. Regis River is shown on the 15-minute USGS St. Regis quadrangle map. This stream no longer exists; it was eliminated in the 1940s by construction of outlet culverts from the north Spectacle Pond to Upper St. Regis Lake. The discharge of the Spectacle Ponds subbasin is through these culverts.

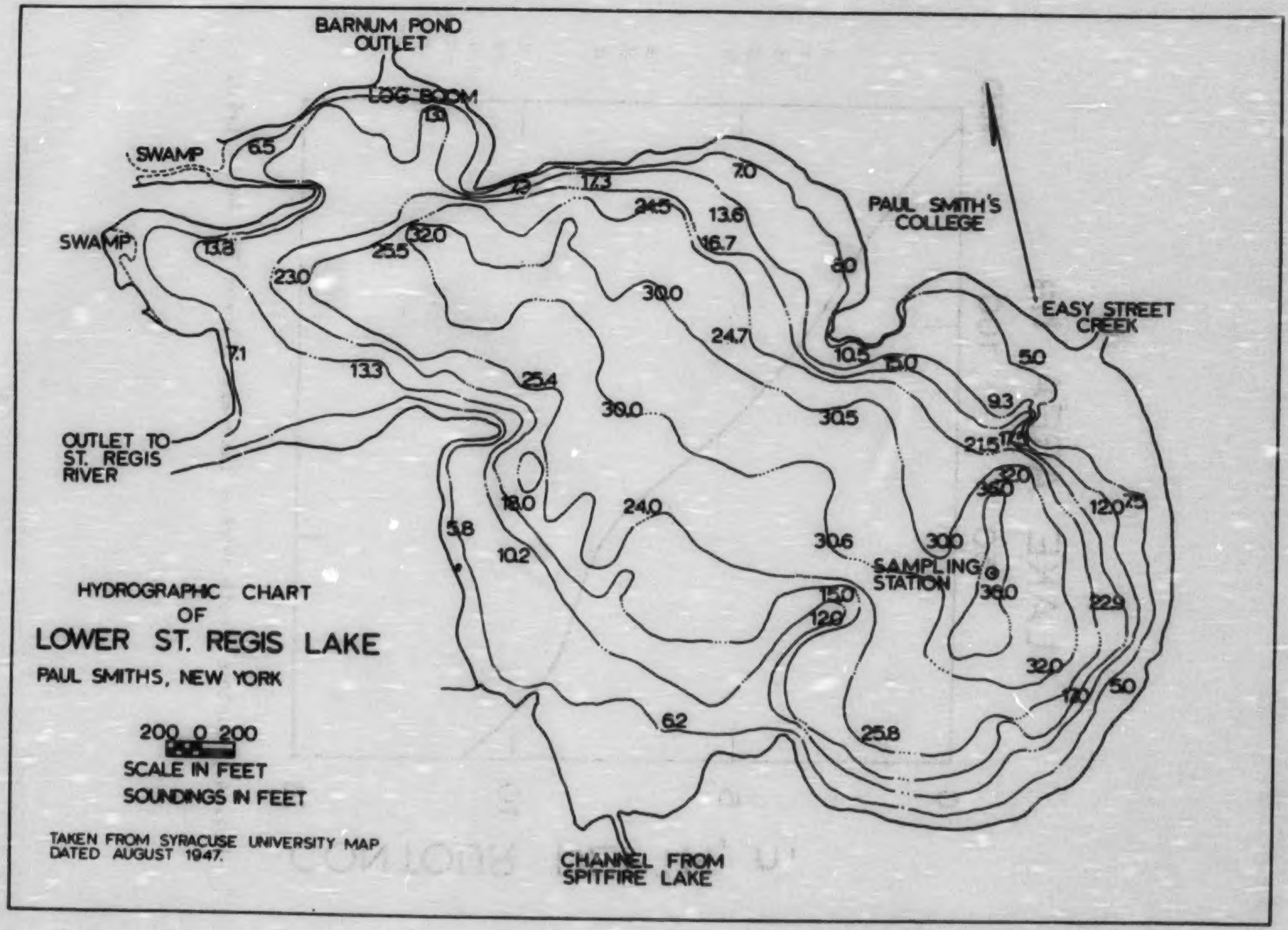

BARNUM POND OUTLET
LOG BOOM
13.0
SWAMP
6.5
SWAMP
13.8
23.0
7.2
17.3
24.5
7.0
13.6
16.7
8.0
PAUL SMITH'S COLLEGE
32.0
25.5
30.0
24.7
EASY STREET CREEK
5.0
10.5
15.0
9.3
7.1
13.3
25.4
30.0
30.5
21.5
17.4
32.0
36.0
12.0
7.5
OUTLET TO ST. REGIS RIVER
18.0
24.0
5.8
10.2
30.6
30.0
SAMPLING STATION
36.0
15.0
12.0
22.9
32.0
17.0
5.0
6.2
25.8
HYDROGRAPHIC CHART OF LOWER ST. REGIS LAKE
PAUL SMITHS, NEW YORK
200 0 200
SCALE IN FEET
SOUNDINGS IN FEET
TAKEN FROM SYRACUSE UNIVERSITY MAP DATED AUGUST 1947.
CHANNEL FROM SPITFIRE LAKE

Fig. 3. Hydrographic chart of Lower St. Regis Lake.

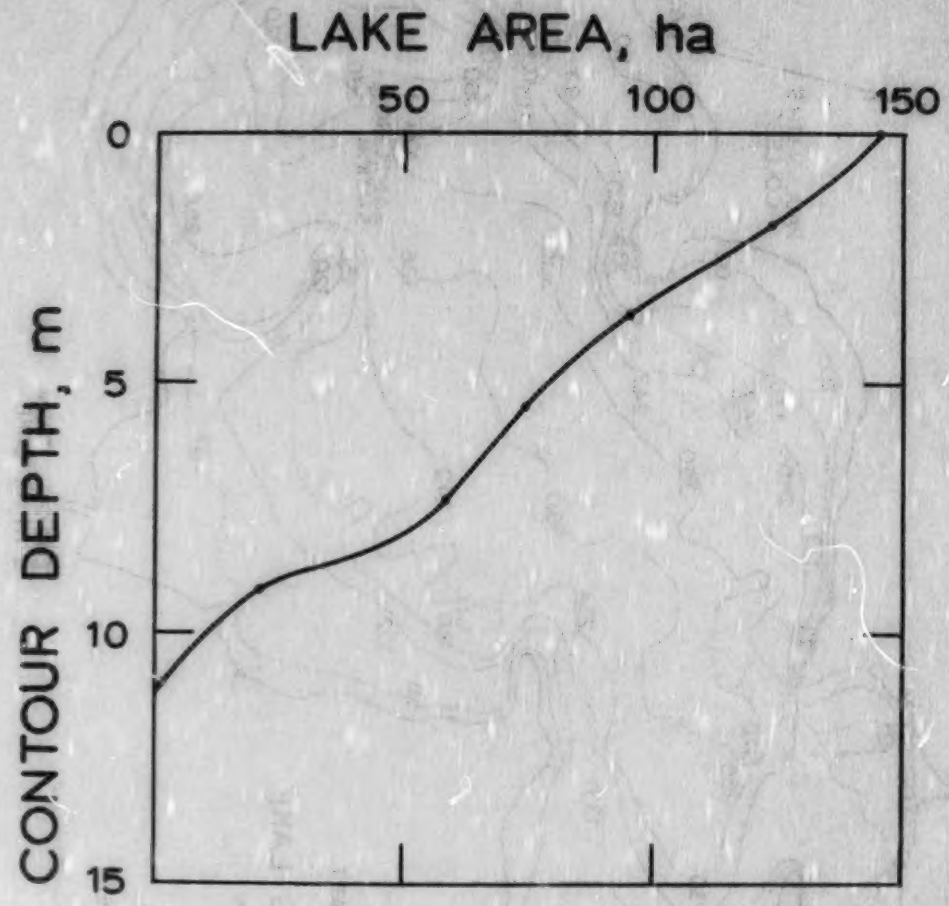
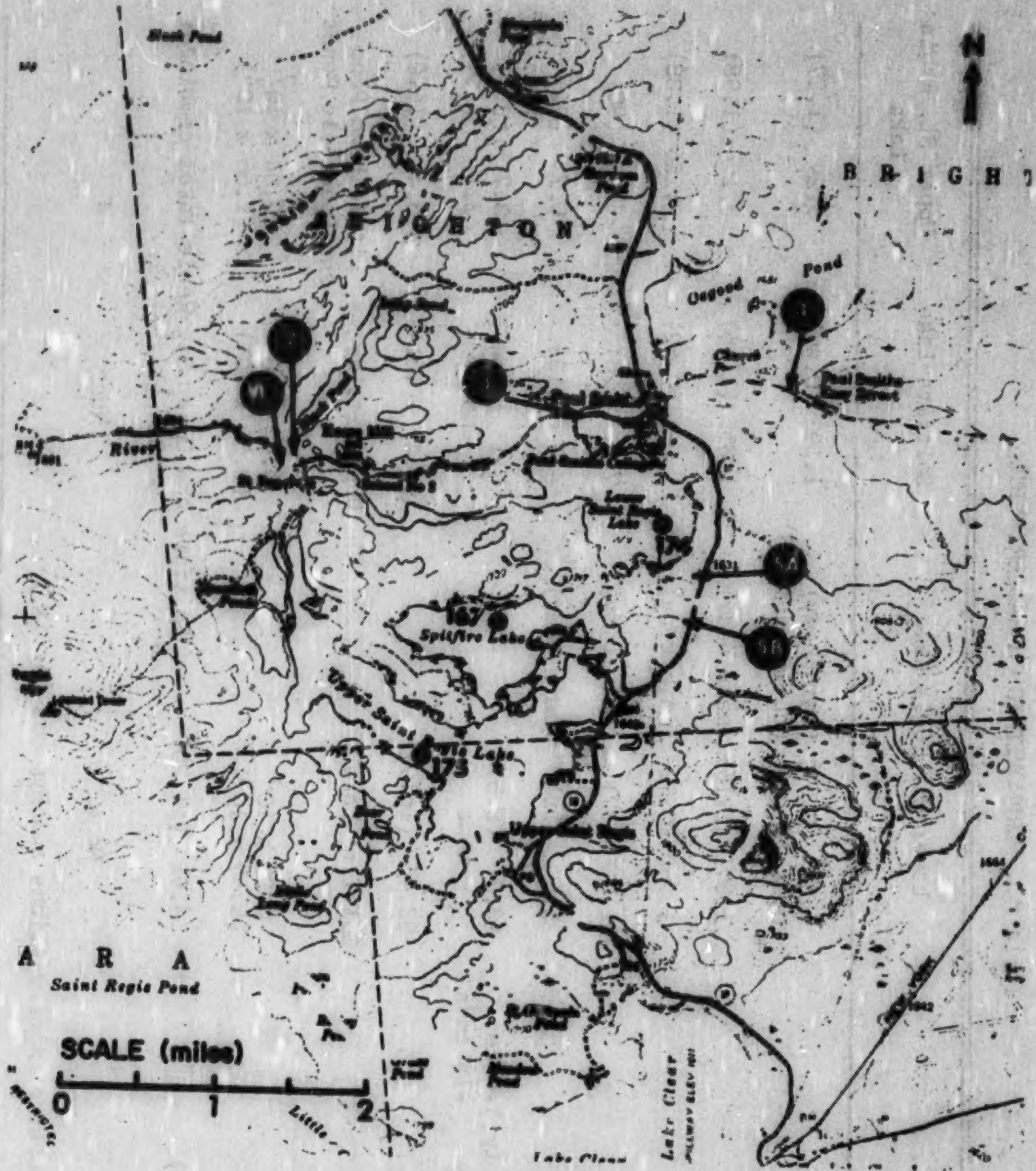


Fig. 4. Contour depth versus lake area, Lower St. Regis Lake.

Table 4. MORPHOMETRIC CHARACTERISTICS

Parameter	Lower St. Regis Lake	Spitfire Lake	Upper St. Regis Lake
Water area, km^2 (mi^2)	1.53 (0.59) (main body) 0.31 (0.12) (outlet arm)	1.19 (0.46)	3.29 (1.27)
Length, km (mi)	1.871 (1.16) (main body)	1.855 (1.15)	3.194 (1.98)
Maximum width, km (mi)	1.258 (0.78) (main body)	1.081 (0.67)	2.226 (1.38)
Maximum depth, m (ft)	11.3 (37) (main body)	7.9 (26)	27.4 (90)
Mean depth, m (ft)	5.6 (18) (main body)	4.1 (13)	6.7 (22)
Length of shoreline, km (mi)-Lake	13.7 (8.5)	7.1 (4.4)	13.7 (8.5)
-Islands	None	None	3.1 (1.9)
Elevation, m (ft)	493.4 (1619)	493.4 (1619)	493.4 (1619)
Largest tributary	Spitfire Lake	Upper St. Regis Lake	Little Long Pond and Spectacle Ponds
Volume, m^3 (a-ft)	8.23×10^6 (6.67×10^3)	4.38×10^5 (3.55×10^2)	2.04×10^7 (1.65×10^4)
Drainage area, km^2 (mi^2)	54.91 (21.20)	Spitfire and Upper St. Regis lakes combined: 30.82 (11.90)	
Islands	None	None	4

Units of measure: see List of Abbreviations and Symbols (p. ix)


N
B R I G H T
Osgood Pond
River
Spitfire Lake
167
173
Upper Saint Regis Lake
A R A
Saint Regis Pond
SCALE (miles)
0
1
2
Lake Clear
1
2
3
4
5A
5B

ST. REGIS LAKES

LAKE STATIONS

174 LOWER ST. REGIS LAKE
167 SPITFIRE LAKE
175 UPPER ST. REGIS LAKE

GAGE STATIONS

1 ST. REGIS RIVER
2 BLACK POND OUTLET
3 BARNUM POND OUTLET
4 EASY STREET CREEK
5A SPITFIRE CREEK NO. 1
5B SPITFIRE CREEK NO. 2

Fig. 5. Drainage basin and location of lake and tributary stations.

GEOLOGY OF THE ST. REGIS AREA

A general review of the geology of the area is given by Alling (1916); a more detailed description is found in Buddington (1953). Lower St. Regis Lake was near the edge of glacial lake Lower Newman. The fine sand with some gravel underlying the flat terrace at Paul Smiths may have been deposited as a delta in glacial lake Lower Newman by melt water flowing from the northeast along crevasses parallel to the edge of the retreating melting ice. The deltaic origin is suggested by the flat terrace. The melt water streams deposited the sand and gravel of the northeast-southwest trending eskers and kames. Lakes, such as Osgood Pond, Church Pond, Cooler Pond, and Lower St. Regis Lake, may be large kettle holes left when ice blocks melted out from under the kame, esker, and delta deposits after glacial lake Lower Newman drained. A northeast-trending esker lies near Paul Smiths.

The bedrock surface suggests the area is located on the southeast wall of a buried valley that bends to the southwest. It may run from the present recharge bed (northeast of Paul Smith's College) toward the mouth of Easy Street Creek and into the present basin of Lower St. Regis Lake. Cooler Pond may lie over this valley.

Davis (1971) reports that the bedrock of the area is anorthosite. This type of rock underlies the rock knob on the point near Paul Smith's College. Buddington (1953) shows syenite outcroppings near Paul Smiths' Easy Street to the east and anorthosite outcroppings north of Osgood Pond. Paul Smiths lies on the west flank of a mass of syenite and gabbro.

Seismic records taken by the New York State Geological Survey in connection with the companion engineering study (Tofflemire, 1975) show low bedrock seismic velocities, which indicate the rock is either highly fractured or weathered.

GROUNDWATER INTERFLOWS

Groundwater flows into and out of the basin along the buried bedrock valley. Some flow may occur in fracture zones in the bedrock. Estimates indicate that groundwater flows are relatively small and can be neglected in water balance calculations.

In conjunction with the construction of the sewage treatment beds, seismic profiles were run, wells installed, and soil samples obtained. As a result, some information exists on subsurface conditions in the vicinity of the beds. This area lies near the drainage divide between Osgood Pond, Church Pond and the lower lake. Since Osgood and Church ponds are at 504 m (1,651 ft) approximate elevation, relative to 494 (1,619) for the lower lake, and the soil is sandy and quite permeable, the possibility of an interflow into the St. Regis basin exists.

An upper limit of 23 liters per second (L $\sec^{-1}$) (0.8 cubic feet per second [cfs]) was obtained by assuming Darcy flow and using maximum possible values for hydraulic gradient, permeability, and area of flow. A more probable value obtained by using average values is 3 L $\sec^{-1}$ (0.1 cfs), which represents only about 0.2% of the mean flow of the St. Regis River.

If interflows exist in the southern end of the basin, they would be cut of the basin, offsetting the inflow from the Osgood Pond area. For example, Roiley Pond is at 494-m (1,620-ft) elevation, versus Little Clear Pond at 487 (1,597), which lies outside of the basin. For these reasons, interbasin flows are considered for the purposes of this study to be zero.

DRAINAGE AREAS

The St. Regis Lakes basin is defined for this study as the entire watershed area above the USGS gaging station on the St. Regis River (USGS designation 04268390). The station is located on the north bank of the river about 305 m (1,000 ft) downstream from the old power-dam outlet of the lower lake.

The drainage areas (Table 5) were obtained by planimetry from USGS 1:62,500-scale topographic maps. Many of the values were verified by the Albany USGS office.

FLOW RECORDS, LAKE LEVELS

Unfortunately, the St. Regis basin does not lend itself easily to gaging. Stream gaging stations were established for the St. Regis River, Barnum Pond outlet stream, Black Pond outlet stream, Easy St. Creek, and two small unnamed creeks referred to as Spitfire Creek No. 1 and No. 2.

The St. Regis River gaging station consists of a stilling well and a continuous recorder (initially a continuous chart recorder, now a punch-tape recorder). All the other gage stations consisted of staff gages which were intended to be read once a day. However, there were many days when readings were omitted, so daily staff gage readings are not complete. All these gages are still in place.

The St. Regis River flow records are the most accurate and complete records of this study. For the duration of the study period the records are complete, with only minor exceptions. Flow records for the other staff gage stations are incomplete, and one object of this study was to fill in the gaps for the daily flow values (see p. 23).

Radiotransmitting gages were available in the second half of the study but were unreliable, mainly due to difficult gain settings in response to atmospheric conditions. Change from AM to FM operation alleviated the problem, and performance runs were successful toward the end of the second year of the study. The flow calculations in this report were developed after the first year of the study and therefore do not utilize any telemetered information.

The Barnum Pond subbasin is about 7.77 square kilometers (km^2) (3 square miles [mi^2]), a considerable portion of the gaged area within the basin. Unfortunately, the flow records could not be utilized in this report. The gage was located only about 300 m upstream from the lower lake and apparently was affected by the lake level. This "backwater" effect was previously suspected by both USGS and our personnel, and further analysis of the flow records confirmed the problem.

Table 5. ST. REGIS LAKE STUDY, DRAINAGE AREAS
(km^2 [mi^2])

Total area of Lower St. Regis Lake drainage basin	54.91	(21.20)[a]
Total area of lower basin (Lower St. Regis Lake)	24.09	(9.30)
Total area of upper basin (Upper St. Regis Lake and Spitfire Lake)	27.20	(10.50)
Total area Spectacle Ponds basin	3.63	(1.40)
Total land area of Lower St. Regis Lake drainage basin	46.88	(18.10)
Land area lower basin	21.65	(8.36)
Land area upper basin	21.96	(8.48)
Land area Spectacle Ponds	3.26	(1.26)
Gaged stations basin area (above USGS staff gage)		
Spitfire Creek No. 1	1.01	(0.39)[b]
Spitfire Creek No. 2	0.91	(0.35)[b]
Easy Street Creek	1.97	(0.76)[a]
Barnum Pond	7.69	(2.97)[a]
Black and Long Ponds	4.14	(1.60)
Total water areas	8.03	(3.10)
Barnum Pond	0.34	(0.13)[a]
Black Pond	0.31	(0.12)[a]
Long Pond	0.05	(0.02)[a]
Lower St. Regis Lake	1.84	(0.71)[a]
(main body)	1.53	(0.59)
(narrow outlet)	0.31	(0.12)
Upper St. Regis Lake	3.29	(1.27)[a]
Spitfire Lake	1.19	(0.46)[a]
Roiley Pond	0.05	(0.02)[a]
Little Long Pond	0.34	(0.13)[a]
Bear Pond	0.23	(0.09)[a]
Spectacle Ponds (2)	0.34	(0.13)[a]
Unnamed pond	0.05	(0.02)[a]

---

[a] Values verified by United States Geological Survey (USGS), Albany, N.Y.

[b] These areas include a third ungaged stream. The actual areas of Spitfire Creek No. 1 and No. 2 are therefore less than shown.

Spitfire No. 1 and No. 2 are small creeks. During the record period analyzed, Spitfire No. 2 at times had no flow, and Spitfire No. 1 had minimum flows (about 0.85 L sec^{-1} [0.03 cfs]). As expected with small creeks, the flow records are not very accurate. There is a large spread of points for actual gaged flows versus the staff gage readings used in establishing the rating curves. In addition, a third creek is located between Spitfire No. 1 and No. 2, and its drainage area is included in theirs, since it is difficult to delineate separate drainage areas for the three creeks.

For these reasons and because the Spitfire Creeks drain into the upper basin, the Spitfire flow records were not utilized in the general water balance calculations. Since the flows are only a very small part of the total basin flow, there was no discernible effect on the hydrologic values. However gaps in daily flow records were filled in by methods discussed below.

Until spring 1974, the only man-made discharge to Lower St. Regis Lake was from the Paul Smith's College Sewage Treatment Plant, with a flow of 38 to 230 cubic meters per day (m^3 day^{-1}) (10,000 to 60,000 gallons per day [gpd]), all derived from groundwater sources within the basin. Flow from the college now reaches the lake via the recharge beds. Besides the college, Lower St. Regis Lake has less than 10 cottages, whereas the two upper lakes have about 225, served by septic systems ultimately fed by well water from the immediate vicinity.

Daily lake level readings were obtained from a staff gage located at Paul Smith's College dock on Lower St. Regis Lake. Paul Smith's College personnel regulate the flow of the St. Regis River and the lake level and maintain lake level records from a staff gage located at the outlet of the lower lake. Although the two gages are located about 4.0 km (2.5 mi) apart, the readings correlate very well. As a result, by using the two separate sets of lake level readings, missing gaps in the lake level readings could be filled in.

PRECIPITATION

A continuous-reading precipitation gage is installed at Paul Smith's College, which is inside the Lower St. Regis Lake drainage basin. The nearest existing U. S. weather station is at Gabriels, approximately 5.6 km (3.5 mi) east of Lower St. Regis Lake.

During the period of interest, records exist for the Paul Smiths station from April to November 1973. Readings were discontinued during the winter of 1973-74 and resumed in late April 1974.

Precipitation records from the Paul Smiths and Gabriels stations were compared for the period April to November 1973. In general, there is little agreement between recorded precipitation values for the two stations, with only a few exceptions. The problem appears to be with the Paul Smiths station, where many periods of data are missing, apparently due to equipment problems, personnel inexperience, and various other factors. Also, there are quite a few obvious errors in the data as reported.

For July and September 1973 the precipitation data for both stations agree quite well. This indicates that precipitation patterns are similar for the Paul Smiths area and the Gabriels area, and the Gabriels station data can be considered applicable to the St. Regis Lake study area. Annual and monthly precipitation amounts can be expected to be similar. However, the agreement would be expected to less close in shorter time frames; daily amounts especially may not agree. As a result, daily precipitation values for the St. Regis Lake basin were obtained by using the Gabriels station data.

LAKE EVAPORATION

Because of the method chosen to compute the water balance in the basin, only lake evaporation values were required, not values for total evapotranspiration over land and water.

Canton, about 74 km (46 mi) west of the St. Regis Lakes basin, is the nearest weather station where pan evaporation is measured. Gabriels, about 5.6 km (3.5 mi) east of the basin, is the nearest station where temperature is measured. In order to obtain daily lake evaporation values, Canton pan values were utilized with an assumed pan coefficient of 0.70 (Chow, 1964). We considered this more accurate than utilizing temperature data from the Gabriels station plus an empirical method for estimating evaporation and then extrapolating to the St. Regis Lakes basin.

For water year 1973 (October 1972-September 1973) evaporation for the basin was computed to be 49.0 centimeters (cm) (19.3 inches [in]). The Canton pan evaporation value for the same period was 70.6 cm (27.8 in); applying the pan coefficient yields 49.5 cm (19.5 in). Although this is not an independent check, it indicates that using Canton pan values and a coefficient of 0.70 is a reasonable assumption.

FLOW CORRELATIONS, EXTRAPOLATIONS, INTERPOLATIONS

The water balance for the St. Regis Lakes basin was computed utilizing hydrologic records from October 1, 1972, through March 31, 1975, a period of 911 days. Existing records from August 21 through September 30, 1972 are not complete enough to be included in the analysis. The present model is based on information obtained as of March 31, 1975.

The main purpose of the correlations, extrapolations, and interpolations was to fill in missing data. The records for the St. Regis River are essentially complete, but all the other stations have some gaps in the daily records.

For 1-day gaps in the data, linear interpolation was used when flow was decreasing. For increasing flow with no precipitation, the preceding day's flow was used. When precipitation occurred, the following day's flow was used.

In order to fill in gaps larger than 1 day, numerous correlations between pairs of variables (flows, precipitation, lake levels) were attempted. The correlations were obtained by linear regression, fitting six different-type curves by the least-squares method. The highest correlation coefficient obtained for each correlation is shown in Table 6.

Table 6. ST. REGIS HYDROLOGY MATRIX
Best correlation coefficients obtained by linear regression; 6 curve types fitted. Total record period: 21 Aug 72 to 31 Mar 74.

	St. Regis R.	Barnum Pond	Black Pond	Easy St. Creek	Spitfire No. 1	Spitfire No. 2	Lake level	Precipi-tation
St. Regis River		0.216	0.538	0.263	0.433	0.093	0.029	0.027
Barnum Pond	0.216						0.792	
Black Pond	0.538			0.232			0.064	
Easy St. Creek	0.263		0.232		0.454			0.536
Spitfire No. 1	0.433			0.454		0.541		0.171
Spitfire No. 2	0.093				0.541			
Lake level	0.029	0.792	0.064					0.175
Precipitation	0.027			0.536	0.171		0.175	

Table 6 (continued). ST. REGIS HYDROLOGY MATRIX

Other correlations (partial record period, seasonal, etc.)

Black Pond vs. St. Regis R.	1 Jan 73 - 31 Dec 73	0.562
	1 Mar 73 - 31 May 73	0.532
	17 Nov 72 - 3 Dec 72	0.334
	2 Aug 73 - 14 Sep 73	0.932
	3 Dec 72 - 11 Mar 73	0.397
	19 Oct 73 - 25 Nov 73	0.655
	15 Jan 74 - 2 Apr 74	0.574
Easy St. vs. Black Pond	19 Oct 73 - 25 Nov 73	0.073
	1 Oct 72 - 19 Dec 72	0.292
	3 Dec 72 - 11 Mar 73	0.275
	7 Nov 72 - 18 Dec 72	0.262
	15 Jan 74 - 2 Apr 74	0.237
Black Pond vs. Easy St.	7 Nov 72 - 18 Dec 72	0.299
Easy St. vs. St. Regis R.	21 Aug 72 - 21 Aug 73	0.337
	21 Aug 72 - 21 Jun 73	0.328
	17 Nov 72 - 3 Dec 72	0.018
	3 Dec 72 - 11 Mar 73	0.333
	19 Oct 73 - 25 Nov 73	0.018
	15 Jan 74 - 2 Apr 74	0.155

Correlations using actual USGS[a] flow data (very limited number of points)

Barnum Pond vs. St. Regis R.	0.584
Black Pond vs. St. Regis R.	0.722
Easy St. vs. St. Regis R.	0.367
Spitfire No. 1 vs. St. Regis R.	0.510
Spitfire No. 2 vs. St. Regis R.	0.168

Other correlations

Spitfire No. 1 vs. St. Regis R.	13 Feb 73 - 19 Jul 73	0.469
Spitfire No. 1 vs. Easy St.	13 Feb 73 - 19 Jul 73	0.594
Spitfire No. 2 vs. St. Regis R.	13 Feb 73 - 19 Jul 73	0.358
Spitfire No. 2 vs. Easy St.	13 Feb 73 - 19 Jul 73	0.760
Black Pond vs. St. Regis R.	1 Oct 73 - 31 Mar 74	0.556[b]

Correlations from computed quantities (hydrologic daily values)

Interlake flow vs. St. Regis River	0.98+
Interlake flow vs. precipitation	0.07
Total ungaged runoff vs. Easy St.	0.28
Total ungaged runoff vs. precipitation	0.15

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[a] United States Geological Survey.

[b] Includes 547 points, no missing data. Includes all interpolated, extrapolated data. Does not change results very much (original matrix yielded 0.538).

In general, there was little or no correlation between hydrologic variables in the period August 21, 1972, to March 31, 1974. Since all the runoff from the basin passes by the St. Regis gage station and the records for that station are the most accurate and complete of the study, we attempted to correlate all the other streams with the St. Regis River. Unfortunately, because the St. Regis River is regulated by man, there is essentially no correlation with the flows of the other streams. Similarly, there is correlation between precipitation and the flows of the various streams.

It was possible to obtain satisfactory correlations (considered satisfactory if the correlation coefficient was greater than 0.5) for partial periods of record, seasonal periods, periods when the St. Regis River outlet was not changed, etc. Many of the gaps were filled in from these correlations.

In some cases judgment had to be exercised in filling in missing data. Strict adherence to the above rules of interpolation, extrapolation, etc. sometimes yielded flows that were obviously in error, and the values were adjusted by the method best referred to as an "educated guess."

WATER BALANCE

A surface runoff approach was chosen from among various possibilities to determine the water balance of the St. Regis Lakes basin. Essentially this approach treats the lakes as a basin and excludes the land from the water balance. The boundary of this basin is defined by the lakes' boundary, and water inputs and outputs are balanced. The St. Regis River receives all the runoff from the basin, which must be equal to the various inputs (streams, surface runoff from the land, groundwater flows) adjusted for storage. The only storage quantity for the basin water balance is that due to changes in lake levels. Precipitation falling on the lake is always an input; evaporation is always an output.

Since the St. Regis River receives the total basin runoff:

$$St = Bl + Ea \pm C_1(L - \bar{L}) + C_2Pr - C_3E + X \quad (1)$$

A more convenient form of equation (1) is:

$$X = St - Bl - Ea \pm C_1(L - \bar{L}) - C_2Pr + C_3E \quad (2)$$

where St = St. Regis River flow

Bl = Black Pond outlet

Ea = Easy Street Creek

L = Lake level

$\bar{L}$ = Lake level from previous day

Pr = Precipitation

E = Evaporation

X = Total runoff from ungaged areas

and the constants are

C_1 = Lake level constant = 73.1 $m^3\ sec^{-1}$ (2582 cfs)

1-m change per day in lake levels for the 6.32-km^2 water area

of the three St. Regis Lakes = 73.1 $m^3\ sec^{-1}$

C_2 = Precipitation constant = 0.731 $m^3\ sec^{-1}$ (25.815 cfs)

1 cm precipitation per day falling on the 6.32-km^2 lakes

area = 0.731 $m^3\ sec^{-1}$

C_3 = Evaporation constant = 0.512 $m^3\ sec^{-1}$ (18.081 cfs)

1 cm evaporation per day from the 6.32-km^2 lakes area X 0.70

(assumed pan coefficient) = 0.512 $m^3\ sec^{-1}$

As mentioned previously, since the Barnum Pond gage is considered unreliable, its records have not been incorporated into the water balance. The Spitfire Creeks flows have also been omitted, as their flows are so small that they have essentially no effect on the water balance. The areas of the Barnum and Spitfire basins are therefore considered to be ungaged.

INTERLAKE FLOW

One aim of this study was to estimate daily flows through the channel separating Lower St. Regis Lake from Spitfire Lake, i.e., the lower basin from the upper basin.

$$A = Z \pm 0.709\ C_1\ (\bar{L} - L) + 0.709\ C_2Pr - 0.709\ C_3E \qquad (3)$$

where A = Interlake flow

Z = Runoff from the upper basin = 0.620 x X (10.17 area of upper basin ÷ 16.40, total ungaged area = 0.620)

and 0.709 is derived by dividing the water area of Spitfire and Upper St. Regis lakes by the water area of the three St. Regis lakes:

$$4.48\ km^2 \div 6.32\ km^2 = 0.709$$

HYDROGRAPHS, HYDROLOGIC QUANTITIES

Daily hydrographs were obtained for the St. Regis River, Black Pond outlet, Easy Street Creek, Spitfire Creek No. 1, Spitfire Creek No. 2, and the interlake flow between Lower St. Regis Lake and Spitfire Lake, for the period October 1, 1972, through March 31, 1975. Other daily hydrologic quantities obtained were precipitation, evaporation, lake levels, total runoff from ungaged areas in the basin, and total runoff from the upper basin. Totals, means, maximums and minimums, and standard deviations were obtained for all these quantities.

DISCUSSION OF RESULTS

In calculating the actual water balance, the only gaged areas were the subbasins of Black and Long ponds and Easy Street Creek, accounting for 6.11 km^2 (2.36 mi^2) out of a total basin area of 54.9 km^2 (21.20 mi^2). The loss of the Barnum Pond subbasin, 7.69 km^2 (2.97 mi^2), was quite serious as it represented a large percentage of the gaged area. The percent of gaged area in the basin must be increased if more accurate hydrologic quantities are desired.

Although daily hydrographs were obtained, the accuracy of a water balance improves as the period of time studied increases; e.g., weekly quantities are more accurate than daily quantities. No consideration was given to such factors as runoff times and times of concentration. This was not normally a problem, since the basin is small, but there were exceptions. For example, when a large amount of rain fell late in the day (or fell at a different time in the St. Regis basin from in Gabriels), the runoff increase was noted the next day. The water balances for the day of the storm and the next day appeared to be in error, but if a water balance was obtained for the 2 days combined, the result was satisfactory. Ultimately the hydrologic quantities will be utilized to measure nutrient balances in the basin. Since the nutrient measurements were obtained once every 2 weeks, the limitations in the daily water balances should not present any problems.

Some correlations among the water balances were attempted using the computed quantities in Table 7. A correlation coefficient of 0.98+ was obtained for the interlake flow versus the flow of the St. Regis River. This is not an independent check; however, the high correlation indicates reasonable values for the interlake flow. As the flow of the river is regulated, the interlake flow must change also, so the results agree with physical reality.

Table 7. SUMMARY OF HYDROLOGY DATA, LOWER ST. REGIS LAKE
($1000\ m^3$)

Year	Month	Prec.	Black Pond	Easy St. Creek	Un-gaged	Inter-lake	Lake storage	Evap.	St. Regis River
1972	Oct	124	46	114	711	1300	11	-77	2230
	Nov	194	154	120	529	981	-146	0	1833
	Dec	242	209	119	802	1858	-17	0	3212
1973	Jan	83	229	105	799	1723	90	0	3029
	Feb	76	169	88	617	1412	90	0	2452
	Mar	96	369	126	1983	3550	34	0	6156
	Apr	209	494	166	1817	3365	-44	0	6006
	May	272	453	147	1418	2294	-140	-140	4304
	Jun	295	458	138	976	1799	-22	-189	3455
	Jul	169	253	124	631	949	6	-207	1923
	Aug	85	64	105	406	653	78	-168	1221
	Sep	294	135	143	566	1607	101	-120	2777
	Oct	106	273	109	484	570	-79	-80	1382
	Nov	178	519	115	424	879	-101	0	2014
	Dec	206	576	148	998	2130	0	0	4057
1974	Jan	126	557	102	742	1929	168	0	3623
	Feb	62	511	91	501	1214	101	0	2478
	Mar	170	630	108	1133	2318	29	0	4387
	Apr	159	692	177	1750	2518	-297	0	4998
	May	196	671	182	1773	3211	45	-110	5967
	Jun	157	409	122	809	1293	-11	-155	2625
	Jul	302	221	137	697	1373	-17	-190	2522
	Aug	186	186	85	755	1497	101	-158	2652
	Sep	223	202	145	562	1195	0	-107	2219
	Oct	75	156	101	382	1921	527	-69	3093
	Nov	188	283	105	694	89	-616	0	743
	Dec	136	300	95	637	1521	62	0	2750
1975	Jan	88	191	94	662	1096	-84	0	2048
	Feb	107	204	82	605	1234	-6	0	2226
	Mar	148	473	88	557	2813	633	0	4712

Prec. = precipitation
Evap. = evaporation

SECTION 7

METHODOLOGY

SAMPLING PROCEDURES

An intensive sampling program was begun in May 1972 and continued through November 1974. The sampling points were close to those of 1971. Station locations (see Fig. 5) were as follows:

Lower St. Regis Lake (174) in the deepest trench of the lake, located centrally in the eastern basin between the entrances of Easy Street Creek and The Slough (channel from Spitfire Lake) at Lat. 44°25'43" N and Long. 74°15'00" W.

Spitfire Lake (167) in the midpoint of the lake at Lat. 44°25'00" N and Long. 74°16'24" W.

Upper St. Regis Lake (175) at the entrance to the northwest arm at Lat. 44°24'09" N and Long. 74°16'19" W (1972 and 1973) and deeper into the arm in the deepest trench at Lat. 44°24'19" N and Long. 74°17'01" W (1974).

1972

Epilimnion and hypolimnion samples were collected from Lower St. Regis and Upper St. Regis lakes at depths determined by temperature profile readings. Composite samples were generally collected at 1 and 3 m (epilimnion) and at two depths in the 7-10-m range (hypolimnion).

Light attenuation readings, Secchi disc readings, and profiles of temperature and dissolved oxygen were recorded on the lakes. The temperature, pH, conductivity, and total alkalinity of each sample were determined in the field. Analyses determined in the laboratory included metals (sodium, potassium, magnesium, total calcium, total iron, total manganese); chloride; sulfate; reactive silica; nitrogen fractions (nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, organic particulate nitrogen); phosphorus fractions (reactive phosphorus, total soluble phosphorus, total particulate phosphorus); organic soluble carbon; and organic particulate carbon. Surveys to assess these parameters were conducted monthly from May to November (biweekly on Lower St. Regis Lake in June and July). Surveys on Lower St. Regis Lake began in May, on the upper lake in June.

Plankton samples were collected weekly (May to November) from Lower St. Regis Lake and monthly (June to November) from Upper St. Regis Lake.

Species were analyzed from both qualitative and quantitative standpoints.

Sediment traps (Fuhs, 1973) suspended approximately 2 m off the bottom were exposed for 2-week periods (June to November) in Lower St. Regis Lake. Separate aliquants from the top and bottom compartments were analyzed for plankton (qualitative and quantitative microscopic analysis) and for the same chemical parameters as the lake water. The results of plankton counts in the traps will be utilized for an analysis of phytoplankton growth and population dynamics in a future publication.

Two tributaries, Easy Street and Spitfire creeks, were sampled biweekly (September to December) and were analyzed for the following physical and chemical parameters: temperature, pH, conductivity, total alkalinity, metals (sodium, potassium, magnesium, total calcium, total iron), chloride, sulfate, reactive silica, and organic particulate carbon. A gage height reading was made during each survey to determine the discharge.

1973

The sampling points and composite sampling techniques were identical to those of 1972. In addition, a composite sample (1 and 3 m) was collected regularly from Spitfire Lake. The epilimnion and hypolimnion depths were essentially the same as those mentioned for the 1972 composite samples.

The physical and chemical parameters measured were identical to those determined on the lake water in 1972. In addition, pH profile, organic soluble nitrogen, total carbon dioxide, chlorophyll a, and humic matter were determined. Surveys were conducted monthly from January to April and biweekly from May to November. Surveys on Lower St. Regis Lake began in January, on the two upper lakes in April.

Plankton samples were collected monthly from January to April and biweekly from May to November from Lower St. Regis Lake. The two upper lakes were sampled biweekly from April to November. Species analysis was performed in the same manner as in 1972.

Sediment traps were collected biweekly (May to November) from Lower St. Regis Lake. Analyses for plankton and chemical parameters were performed as in 1972. Organic soluble nitrogen, chlorophyll a, and humic matter were determined as well.

Easy Street and Spitfire creeks were sampled biweekly (January to December). The same physical and chemical parameters were analyzed as in 1972. In addition, total manganese; nitrogen fractions (nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, total organic nitrogen); phosphorus fractions (reactive phosphorus, total soluble phosphorus, total particulate phosphorus); and organic soluble carbon were determined.

1974

The sampling points and composite sampling techniques were identical to those of 1973. The epilimnion and hypolimnion depths were essentially the same as those sampled in 1973, with the exception of Upper St. Regis Lake, on which sonar equipment was employed at the new station to locate the lake bottom. The composite sample for the hypolimnion was taken at two locations in the 14-22-m range. (On April 25 the lower lake was sampled 500 m off the college dock, as the main station was inaccessible due to ice thaw. Chemical analysis-epilimnion composite from 1 + 2 m; hypolimnion, 3 + 4 m. Plankton analysis-epilimnion biomass represents the average of 1, 2, and 3 m.)

The physical and chemical parameters measured were identical to those determined in 1973. Surveys were conducted at least monthly from February to November (biweekly for Lower St. Regis Lake from May-July and September-October; biweekly for the upper lakes in June and September). Surveys on Lower St. Regis Lake began in February, the two upper lakes in May.

Plankton samples were collected at least biweekly from February to November (weekly or more frequently from July-October) from Lower St. Regis Lake. The two upper lakes were sampled biweekly (May to November). Species analysis was performed in the same manner as in 1973.

Sediment traps were collected biweekly from May to October (except only once in August) from Lower St. Regis Lake. Analyses for plankton and chemical parameters were performed as in 1973 with the exception of chloride and sulfate analyses.

Easy Street and Spitfire creeks and a third tributary to Lower St. Regis Lake, Black Pond outlet, were sampled biweekly (average frequency, January to December). The physical and chemical parameters were as in 1973. In addition, humic matter was determined.

1975

A less intensive sampling program was carried out in 1975. Only Lower St. Regis Lake was sampled. Single depth samples rather than composites were collected at 3-6 m (epilimnion) and 8-11 m (hypolimnion).

Temperature and dissolved oxygen profiles were determined at the main lake station during each monthly (and occasionally biweekly) survey (May to October). Light attenuation and Secchi disc readings were taken periodically during the survey span. The physical and chemical parameters measured were temperature, pH, conductivity, total alkalinity, total dissolved solids, and chlorophylls a, b, and c.

Plankton samples were collected monthly (and occasionally biweekly; May to October). Species were analyzed qualitatively and quantitatively. During the monthly surveys, preserved slides of algal concentrate from the epilimnion station were prepared in the field for cytochemical examination in the laboratory (study in progress; results to be reported elsewhere).

Easy Street and Spitfire creeks and Black Pond outlet were sampled two or three times during February and March. The physical and chemical parameters analyzed were the same as in 1974 except that the following were not determined: metals (sodium, potassium, magnesium, total calcium, total manganese), chloride, sulfate, organic soluble carbon, organic particulate carbon, and in Easy Street Creek humic matter.

PROCEDURES FOR PHYSICAL AND CHEMICAL DETERMINATIONS

Field

Secchi disc readings were made at the lake stations by means of a 30-cm-diameter white Plexiglas disc (Kahlsico Instrument Corp.). Temperature profiles were taken with a calibrated Yellow Springs Instruments (YSI) Model 8400 thermistor. Field pH profiles were taken with a Radiometer Model 4 precision pH meter. Samples for dissolved oxygen determination were put in glass-stoppered bottles to which were added manganese solution, strong alkali, and concentrated acid according to the specifications of the Winkler method (azide modification) described in Standard Methods (American Public Health Assoc., 1971). Solar radiation was measured with a Yellow Springs Instruments direct reading pyranometer equipped with a silicon solar cell which had been factory-calibrated against an Eppley 180° pyranometer.

Vertical light extinction was determined from simultaneous measurements of surface and subsurface irradiation with a submarine photometer (Kahlsico Instrument Corp.). The subsurface measuring cell was used without filters or with one of the following Schott filters: BG 12 (435 nanometers [nm], blue), VG 9 (525 nm, green), or RG 2 (600 nm, red), following procedures recommended by Sauberer (1962). The readings were converted to vertical extinction coefficients (per meter, in base-10 logarithms) using Sauberer's Table 10 with estimated values of cloud cover and a calculated value for the zenith distance of the sun at the time of measurement. The latter value was obtained from declination, true local time, and the geographic coordinates - i.e. the elements of the "nautical triangle" - by spherical trigonometry. Vertical extinction coefficients were further corrected to successive depth values for which measured light intensities decreased by 50% (see Figures 10 and 11).

Samples collected during 1972-1974 were processed on shore within 2 hours of sampling, as follows:

The temperature, pH, and conductivity of the composite sample were determined using a laboratory-grade thermometer, a Radiometer Model 4 precision pH-meter, and a Radiometer Model CDM 2 conductivity meter. Total alkalinity was titrated with mineral acid to an end point using methyl purple indicator.

Titration of the samples for dissolved oxygen determination followed the Winkler method, azide modification (American Public Health Assoc., 1971).

For determination of soluble and particulate nitrogen, phosphorus, and carbon, 300 ml of sample (or less, depending on filterability) were filtered in a Millipore filtering apparatus at a vacuum not exceeding 100 millimeters (mm) of mercury. The 0.8-micron (μ)-pore-width, 47-mm-diameter membrane filters had been boiled and rinsed in distilled water to remove soluble organic components and were stored in distilled water in a closed plastic container. Before the sample was added, the filter was covered with Celite by pouring through it without vacuum 4 ml of a Celite suspension (10 g liter^{-1} distilled water) and discarding the filtrate. After the sample was filtered, the filtrate was distributed into 120-ml polyethylene bottles for soluble nitrogen and phosphorus determinations. For determination of soluble carbon, 4-5 ml of filtrate were placed in a screw-cap glass tube. The bottles used for phosphorus analysis had been washed with a 1:1 solution of concentrated nitric acid and distilled water and then rinsed liberally with distilled water. For particulate nitrogen, phosphorus, and carbon determinations the residue was flushed from the filter using a syringe equipped with a narrow-gage needle and collected in a graduated tube, then made up to 10 ml and divided into screw-cap tubes. All samples were immediately placed on Dry Ice and transferred in a frozen state to the main laboratory in Albany.

For determination of total carbon dioxide, 10 ml of well-mixed sample were transferred into an absorption jar. An open plastic vial containing 1 ml of a 1 normal solution of sodium hydroxide (1 N NaOH) was placed in a plastic beaker inserted into the jar. A pH 2 buffer tablet was dropped into the sample, and the entire jar was tightly capped and taped. A blank was run by placing 1 ml of 1 N NaOH in a plastic vial, capping the vial, and placing it in an empty absorption jar, which was then capped and taped.

Unfiltered samples for metals analysis were acidified and frozen at the shore site. Unfiltered samples for reactive silica and humic matter determinations were also frozen at the shore site for transport to the Albany laboratory. Observations by Kobayashi (1967) that freezing can cause loss of silica from solution came to our attention later and our results may therefore be low. Unfiltered samples for chloride and sulfate analyses were kept at ambient temperature.

For chlorophyll determinations, 250 ml (or less, depending on filterability) of sample were filtered through a 0.8-μ-pore membrane filter which had been covered with magnesium carbonate ($MgCO_3$) by prefiltering it with 4 ml of a $MgCO_3$ suspension (10 g liter^{-1} distilled water). After filtration of the water sample at a vacuum not exceeding 100 mm of mercury, the filter was removed, placed in a tightly capped centrifuge tube in a light-tight box, and kept on Dry Ice until arrival at the Albany laboratory, where the box was transferred to a freezer. Prior to analysis, 10 ml of freshly diluted 90% acetone was added to each tube, which, tightly capped and replaced in the light-tight box, was kept in a refrigerator until chlorophyll extraction was complete. Analysis was performed within 24-48 hours after the acetone was added.

During the 1975 surveys, determinations of temperature and pH at the laboratory, conductivity, alkalinity, total dissolved solids, and chlorophyll were performed at the Environmental Health Center Field Laboratory at Ray Brook.

Laboratory

Unless otherwise indicated, all laboratory determinations were performed at the Environmental Health Center facilities in Albany.

Change in specific conductance with change in temperature of Lower St. Regis water was measured empirically within the laboratory. The slope of the regression of conductivity on temperature showed an increase of

1.534 micro-Siemens per centimeter (µS cm^{-1}) per degree Celsius (°C) within the range of 40 to 100 µS cm^{-1}. Correction of conductivity results to 25°C was then calculated as: Conductivity at 25°C = Conductivity at t + 1.534 (25-t), where t equals the actual temperature.

The following metals were determined by atomic absorption spectrophotometry (Varian-Techtron Model AA5 spectrophotometer) using an air-acetylene flame (Perkin-Elmer 1968, Parker 1972): sodium, 589.0 nm, potassium, 766.5 nm; magnesium, 285.2 nm; manganese, 279.4 nm; and iron, 248.3 nm. Calcium, 422.7 nm, was determined by the same system using a nitrous oxide-acetylene flame.

Total iron was determined by adding calcium ion (Ca^{2+}) and 1.0 ml of concentrated hydrochloric acid (HCl) per 50 ml of sample. The sample was then heated for approximately 1 hour on a steam bath before analysis by atomic absorption. Samples for calcium analysis were acidified with HCl to pH 4.5 or lower several hours before analysis.

Chlorides were determined in an AutoAnalyzer (Technicon). The method involved complexation of mercury by chloride, resulting in the release of thiocyanate, which reacts with ferric ion to form ferric thiocyanate (U. S. Environmental Protection Agency, 1971; American Public Health Assoc., 1971).

Sulfates were determined in the AutoAnalyzer. The automated colorimetric methyl-thymol blue method by Lazrus et al. (1966) was used with slight modifications to determine sulfates (ranges 0-500 or 0-1500 milliequivalents per liter [meq $liter^{-1}$]).

Nitrogen fractions were determined as follows: Nitrate plus nitrite nitrogen was measured by AutoAnalyzer technique using a 50-mm flow cell. The method involved reduction to nitrite, followed by sulfanilic acid diazotization and formation of azo-dye (Strickland and Parsons, 1968). Nitrate nitrogen was determined as part of this procedure. Ammonia nitrogen was also determined by AutoAnalyzer technique. The method involved formation of indophenol blue from ammonia, phenol, and hypochlorite, with sodium nitroprusside as a catalyst (Solórzano, 1969). Soluble organic nitrogen was obtained by filtering samples through 0.8-µ-pore membrane filters and subjecting the filtrate to micro-Kjeldahl nitrogen determination according to Standard Methods (American Public Health Assoc., 1971). Particulate organic nitrogen was measured by micro-Kjeldahl digestion and direct colorimetric determination of ammonia by the indophenol blue reaction in the highly standardized procedure of Bohley (1967), scaled up slightly for use with the Celite-containing suspensions of seston.

Phosphorus fractions of samples collected in 1970 and 1971 were determined according to the following methods: Reactive phosphorus (essentially orthophosphate) was determined according to Murphy and Riley (1962). The method involved formation of phosphomolybdate complex and was carried out on the AutoAnalyzer. For total soluble phosphorus, filtrates were heated with sulfuric acid and potassium persulfate for 30 minutes, brought back to volume (Gales et al., 1966), and assayed for reactive phosphorus. For total particulate phosphorus, samples were subjected to alkaline persulfate digestion

(Fuhs, 1971), followed by acid digestion (Gales et al., 1966), and assayed for reactive phosphorus. All St. Regis samples collected since 1972 were analyzed according to Canelli and Mitchell's (1975) procedures based on the above methods.

Reactive silica was determined on a Bausch and Lomb Spectronic 400 spectrophotometer utilizing the heteropoly blue method C (without sodium bicarbonate digestion) as described in Standard Methods (American Public Health Assoc., 1971).

Soluble organic carbon was determined by combustion in a tube furnace and infrared analysis of carbon dioxide according to the modification by Fuhs (1969). Particulate organic carbon was measured by oxidation of a portion of the HCl-treated, Celite-containing filter deposit in an induction furnace, using the same CO_2 indication system (Fuhs et al., 1972). On samples collected after June 1974 an Oceanographic International Corp. carbon analyzer was used with persulfate oxidation of filtrates and Celite slurry respectively.

Total CO_2 was determined by a microdiffusion method with NaOH as the absorbent, injection of a portion of the NaOH into acid, and measurement of CO_2 released by infrared analysis.

Chlorophyll a samples collected in 1973 and 1974 were determined by 90% acetone extraction and spectrophotometry (Bausch and Lomb Spectronic 100 spectrophotometer). Absorbence was determined in a scanning spectrophotometer, and readings at 750, 663, 645, and 630 nm were introduced into Strickland and Parsons' (1968) formula. The samples collected in 1975 were determined at the Environmental Health Center Ray Brook Field Laboratory by the same method on a Bausch and Lomb Spectronic 70 nonscanning spectrophotometer. Calculations of chlorophylls b and c were made according to the SCOR/UNESCO formulas given by Strickland and Parsons (1968, p.189).

Humic matter was determined by extraction from an acid solution into n-butanol, reextraction into dilute NaOH, and photometry of the resulting solution according to the method of Chalupá (1963).

Total dissolved solids was determined by filtering the sample through a 0.8-μ-pore width membrane filter within 3 hours after collection and obtaining the gravimetric weight of the filtrate, according to the method described for filtrable residue in water in Standard Methods (American Public Health Assoc., 1971). This test was run in 1975 by the Environmental Health Center Field Laboratory at Ray Brook.

Analytical methods for lake and tributary samples were identical, with the following exception. On tributary water organic nitrogen as a whole, rather than its soluble and particulate units, was determined. For samples collected before April 26, 1973, organic nitrogen represents total Kjeldahl nitrogen (TKN) less any ammonia-nitrogen present in the filtered sample. Since this date TKN was performed on a grab (unfiltered) sample.

MICROSCOPIC ANALYSIS OF PLANKTON

A microscopic examination was performed on each plankton sample to identify and quantify the major phytoplankton species.

The Utermöhl inverted microscope technique employed is based on information from Utermöhl (1936, 1958), Lund and Talling (1957), and Lund et al. (1958). A 100-ml portion of sample was preserved in the field with 1.0 ml of Lugol's solution (10 g iodine, 20 g potassium iodide, 27 g sodium acetate, and 200 ml distilled water). A raw sample was also collected for examination of plankton in a live state during a 1-year period which began in October 1973.

Centrifugation and/or sedimentation was used to concentrate the plankton. Up to 10 ml of sample can be concentrated directly in the plankton chamber; Lugol's solution helps to weight the algae and insure their sedimentation. Usually 10 ml were sufficient, but for various samples 5 to 40 ml were used. The particle concentration was the major determinant of the sample volume used. If a greater concentration was necessary, up to 40 ml were centrifuged at 1,500 revolutions per minute (rpm) for 20 minutes, after which the supernatant was drawn off, leaving 10 ml of concentrate. The tube of concentrated plankton was placed briefly on a Vortex-Genie to obtain a well-mixed solution and then transferred to a 10-ml plankton settling chamber. The chamber was inverted one to three times to allow even distribution of settling particles. Sedimentation time was a minimum of 7.5 hours for a 10-ml volume of sample (3 hours per cm-height of chamber: see Vollenweider, 1969) before microscopic analysis was begun.

The most numerous and largest plankton organisms were identified to genus or species using a Wild M 40 inverted microscope. Strip or field counts were made with magnification from 90 to 750X. A minimum count of 30 cells or colonies of a species was the goal. Scarce organisms were recorded qualitatively. The principal reference used for plankton identification was Prescott (1962).

The mean area and volume were calculated by using a geometric formula which corresponded to the shape of the cell or colony. Five basic shapes were used singly or in combination: sphere, prolate spheroid, cylinder, cone, and regular prism (particularly rectangular prism). Specific dimensions were measured on 5 to 10 cells or colonies of each species by use of an ocular micrometer rule. A Wang 720 C programmable calculator was employed to process the raw data and to calculate cell or colony number per ml, areal standard units per ml, and volume as cubic millimeters per liter (mm^3 $liter^{-1}$).

SECTION 8

RESULTS

PHYSICAL CHARACTERISTICS OF LOWER ST. REGIS LAKE

Temperature

Lower St. Regis Lake is ice-covered from December to April. Thermocline formation occurs during May at lake temperatures of 4 to 8°C. In 1973 the main thermocline moved to 4-5 m depth in July and to 5-6 m in August. Surface temperatures in summer are typically between 20 and 25°C, with the possible formation of secondary thermoclines. Thermocline erosion over the period of sudden onset of the blue-green algal bloom is not particularly noticeable and may amount to 1 m per month. In mid-October cooling and wind lead to fall overturn with lake temperatures between 5 and 10°C. Temperature data for Lower St. Regis and Upper St. Regis lakes are summarized in Figures 6 and 7.

Dissolved Oxygen

In 1972 dissolved oxygen was exhausted to 9-m depth in July and to 8-m depth in September. In 1973 the depletion reached the thermocline by mid-August (5-7 m). In 1974 the thermocline was deeper, and the hypolimnion was devoid of oxygen to 9-m depth by the end of July (Fig. 8). Some depletion of oxygen occurs in the near-bottom waters under ice cover in winter, as indicated by measurements in February 1973. Data for Upper St. Regis Lake are presented for comparison (Fig. 9).

pH Values

pH values in the epilimnion are strongly affected by time of day. During bloom periods, daytime values of 8.0 to 9.5 were observed, with hypolimnion values of 5.8 to 7.5. Upper St. Regis Lake showed slightly lower values, (6.0 to 8.5, occasionally up to 9.2), in accordance with both lower productivity and lower alkalinity.

Light Attenuation

Light attenuation at 660 nm in the water columns of Lower St. Regis Lake (Fig. 10) and Upper St. Regis Lake (Fig. 11) reflects bloom development in considerable detail. Since most of the water entering the lower lake passes through the upper lakes or through swamps, turbidity from suspended mineral matter is rarely noticeable in the epilimnion. Some mineral suspended matter was, however, observed in the samples from the hypolimnion.

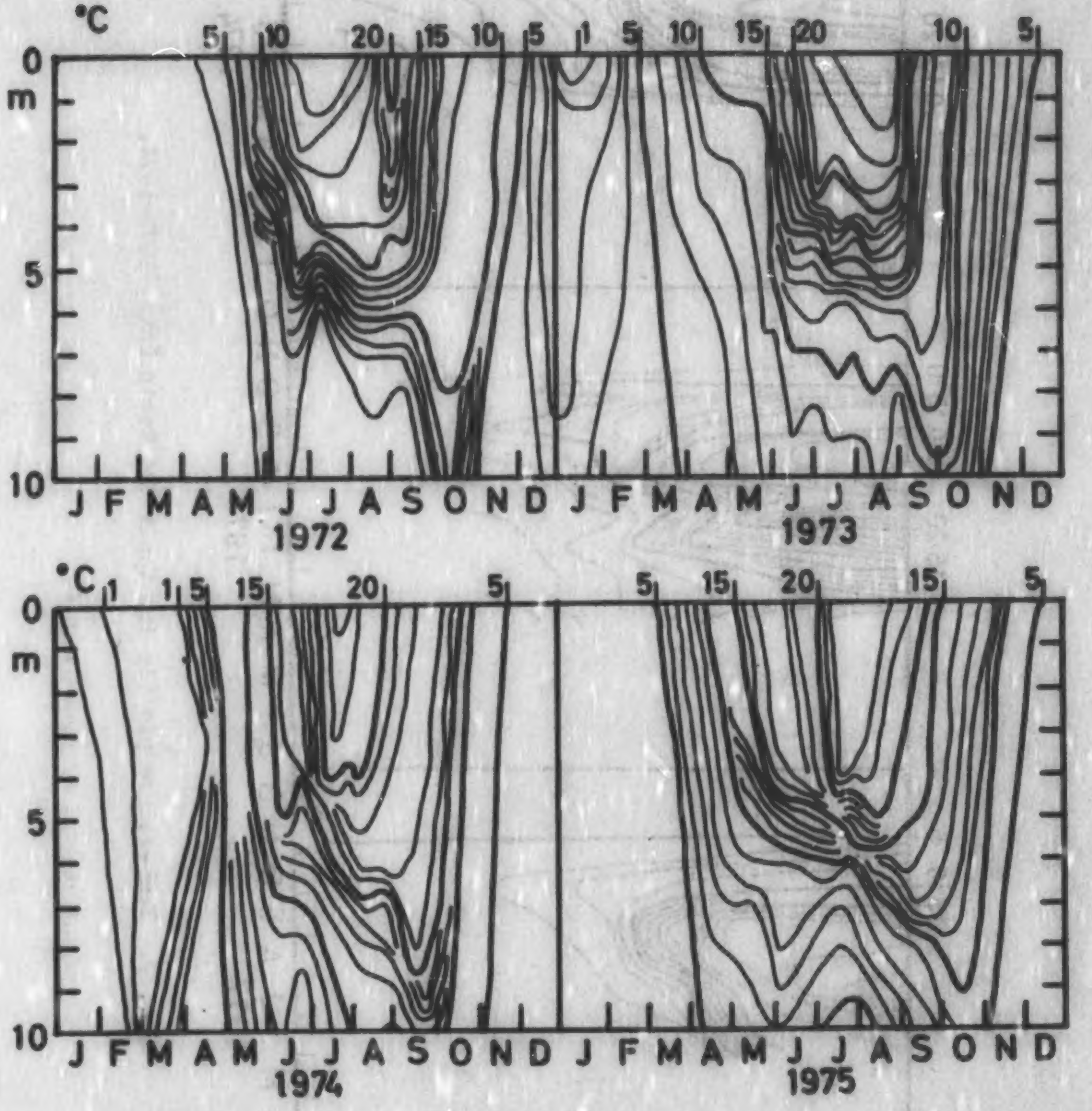

Fig. 6. Temperature profile for Lower St. Regis Lake, 1972-1975.

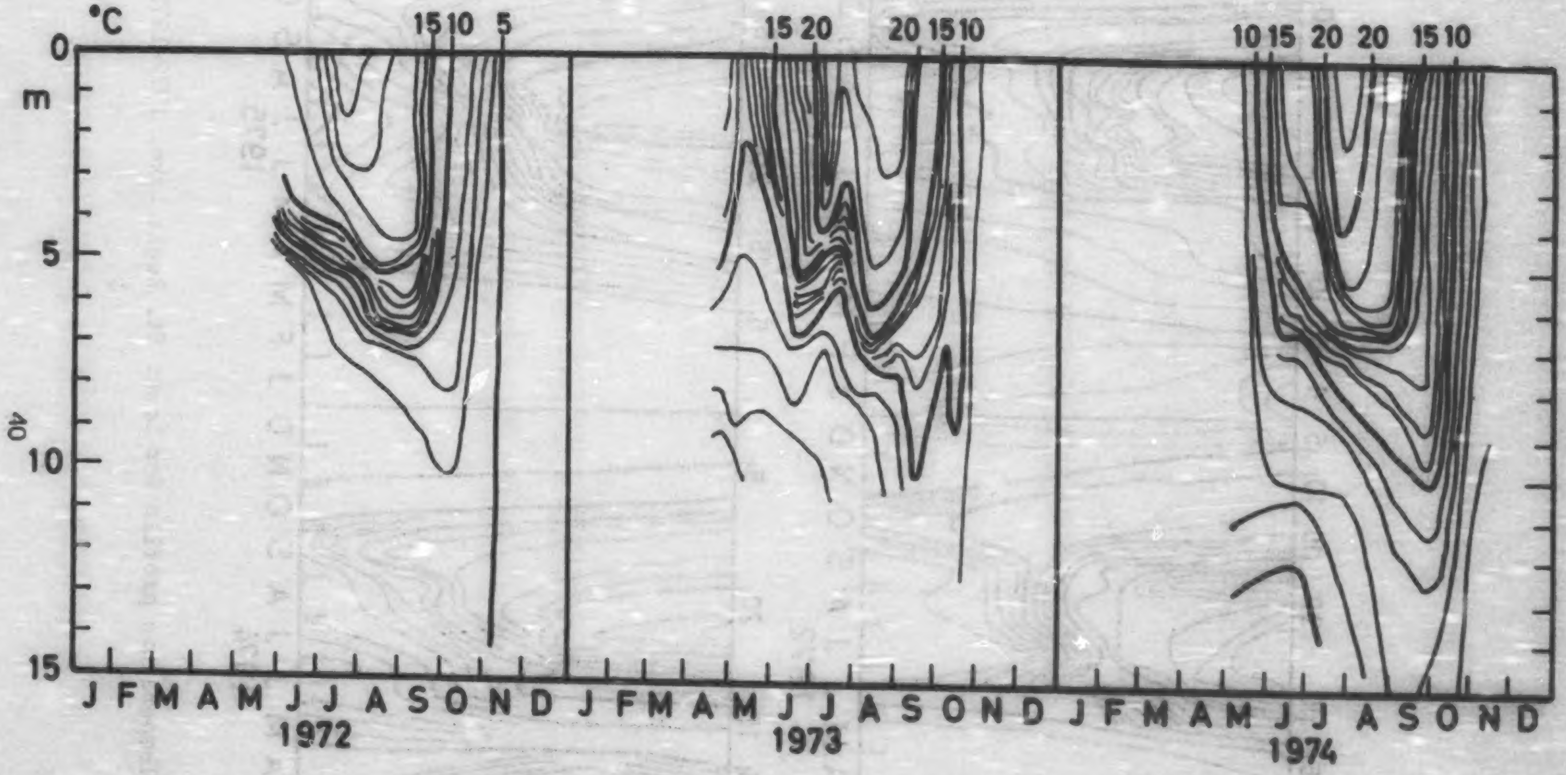

Fig. 7. Temperature profile for Upper St. Regis Lake, 1972-1974.

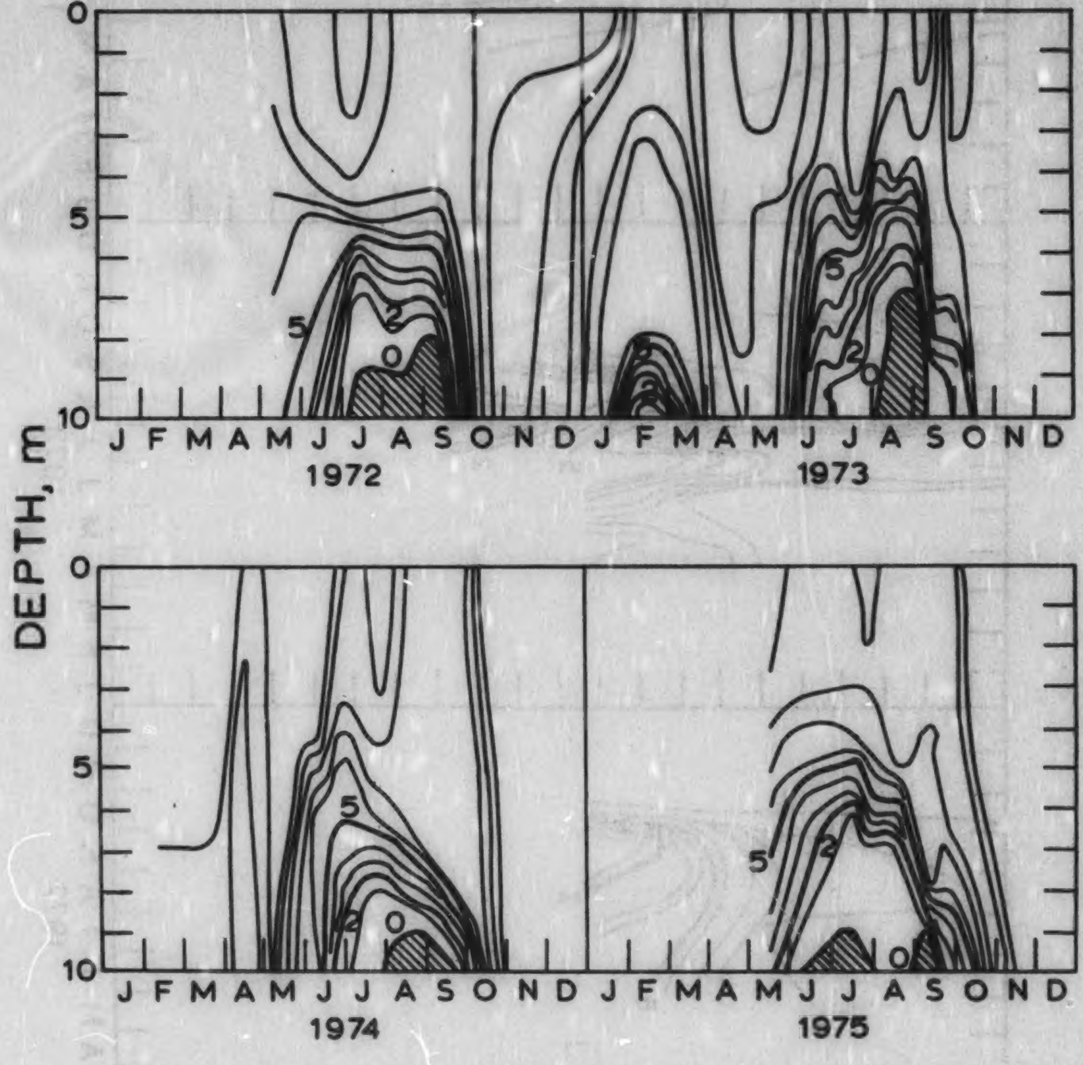

Fig. 8. Dissolved oxygen data (mg · liter^{-1}) for Lower St. Regis Lake, 1972-1975.

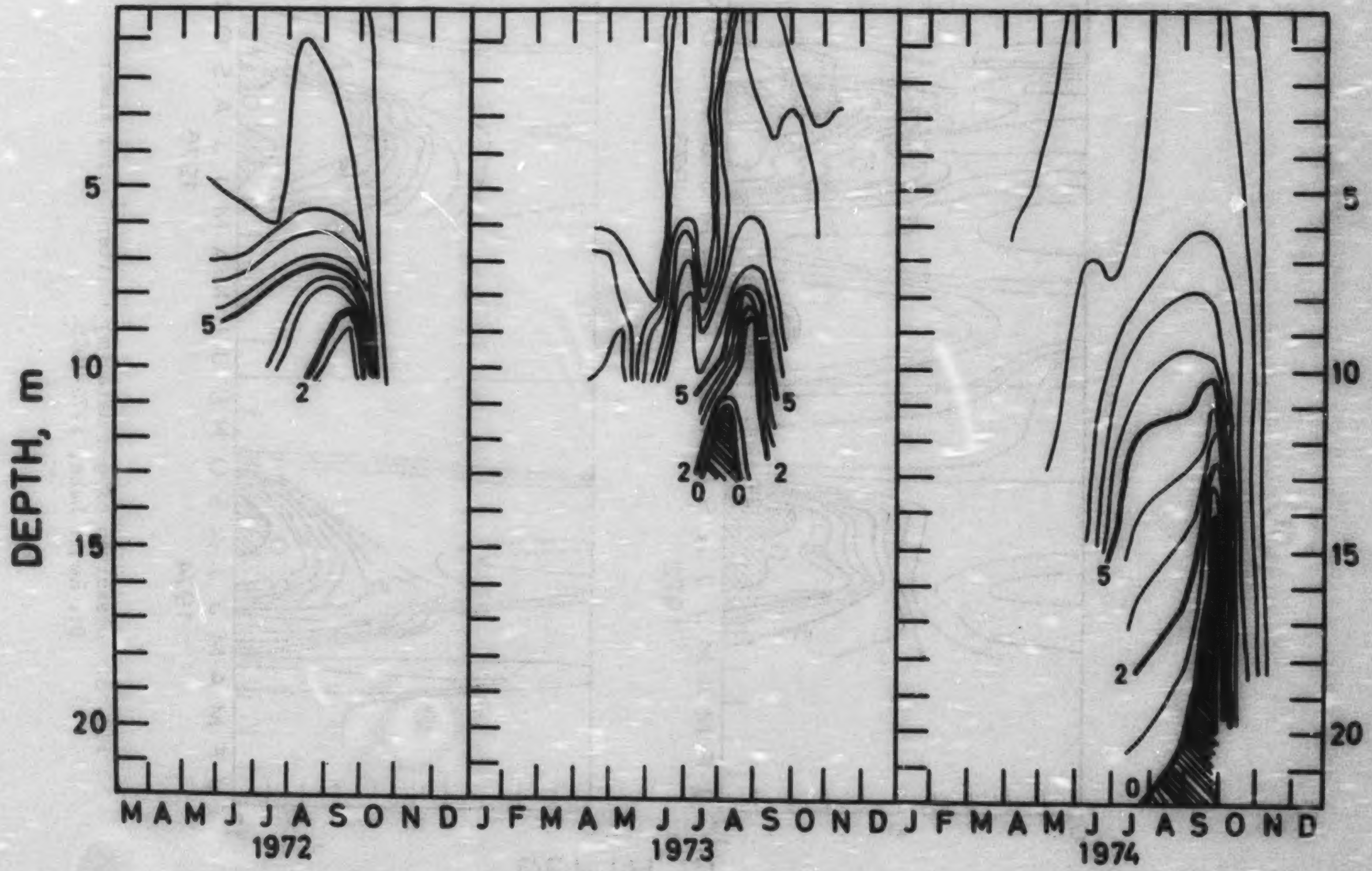

Fig. 9. Dissolved oxygen data (mg · liter^{-1}) for Upper St. Regis Lake, 1972-1974.

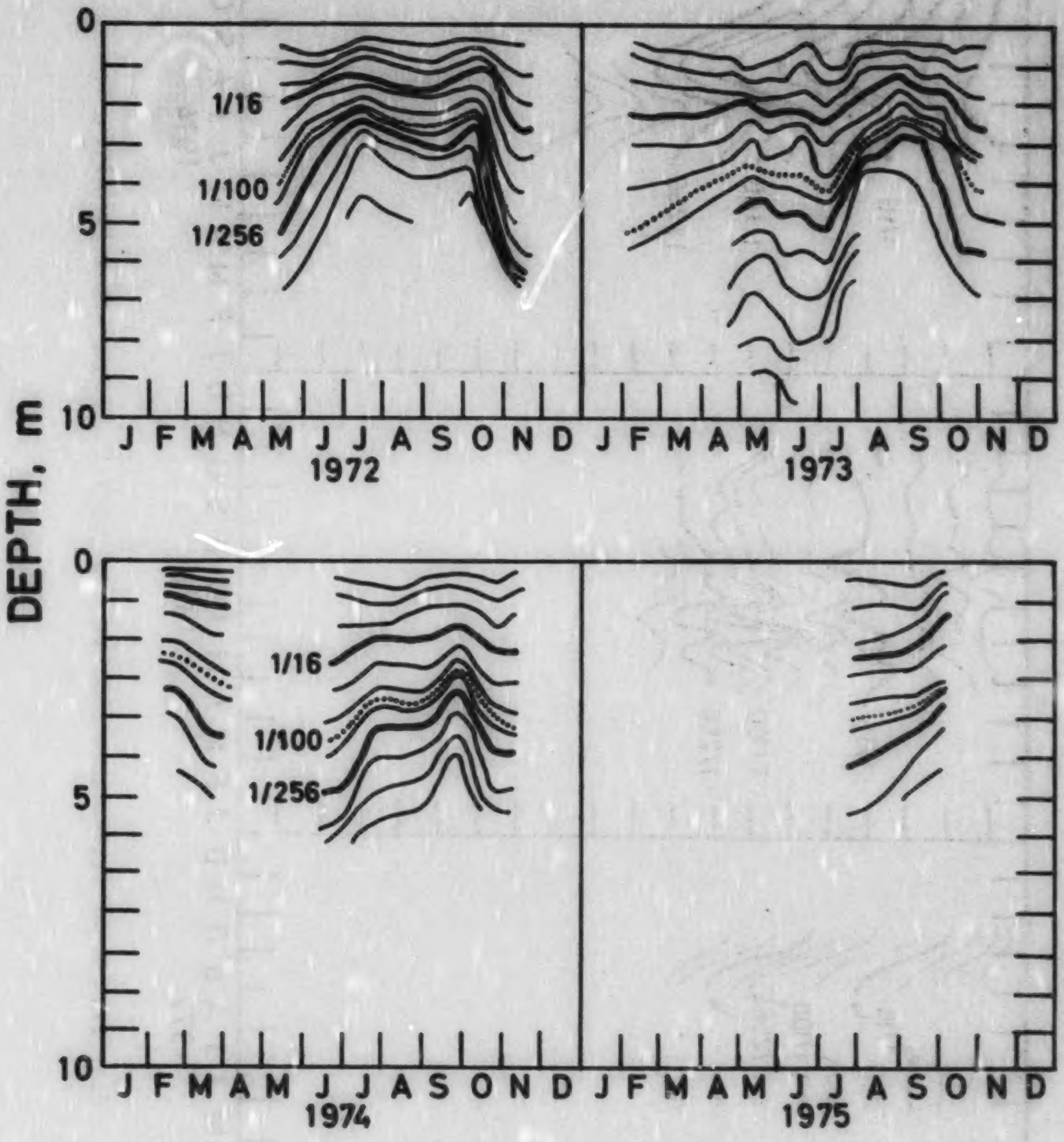

Fig. 10. Light attenuation (660 nm) for Lower St. Regis Lake, 1972-1975.

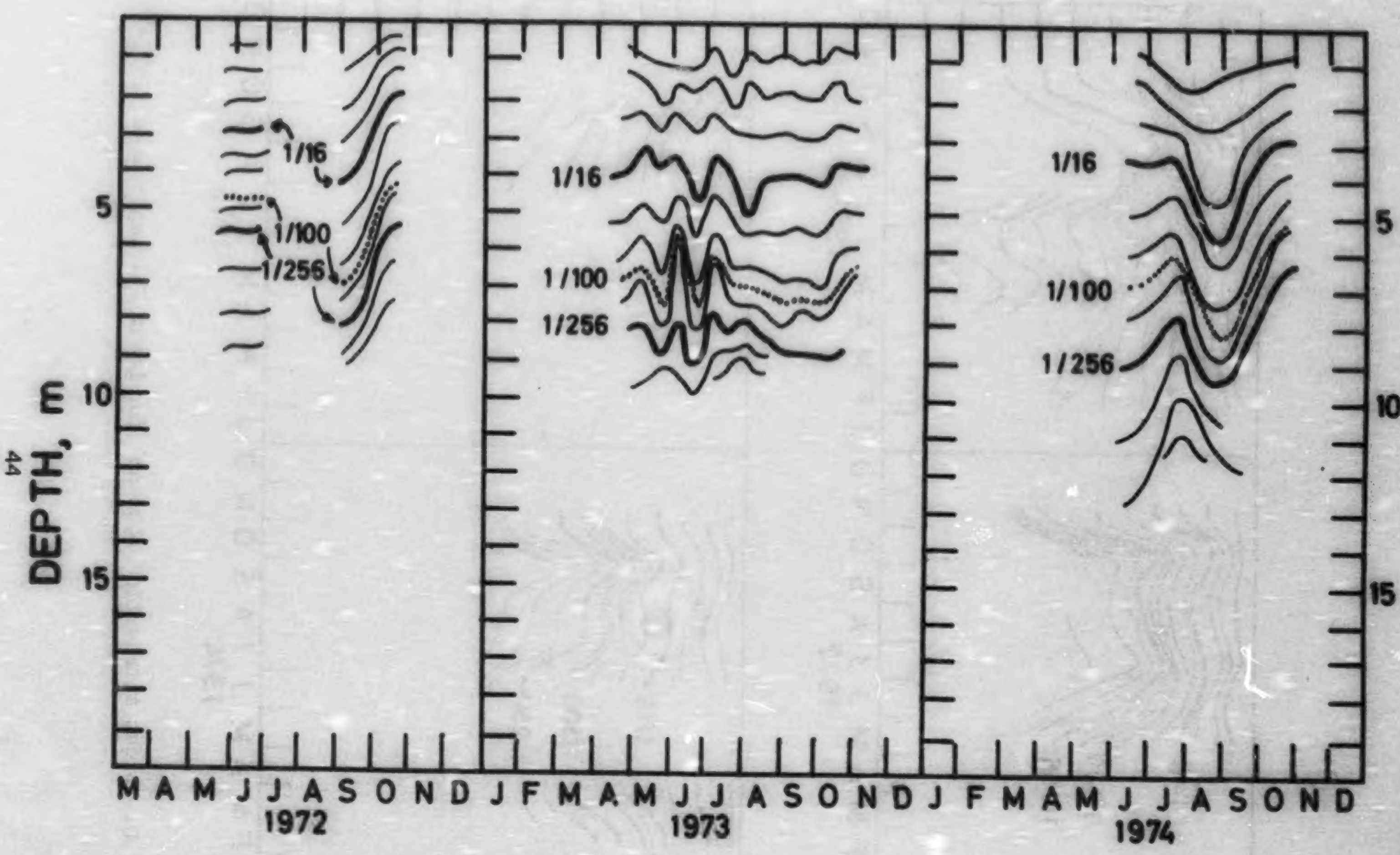

Fig. 11. Light attenuation (660 nm) for Upper St. Regis Lake, 1972-1974.

The general increase in transparency in the 660-nm (red) region during 1973-75, particularly during August and September (Fig. 10), indicates reduced bloom conditions. Transparency increased to the extent permitted by the naturally brown color of the water.

LAKE CHEMISTRY

Major Ions

The St. Regis Lake system contains low-alkalinity water with approximately 0.4 meq liter^{-1} total ionic content and with the relative ionic composition shown in Table 8.

Table 8. RELATIVE IONIC COMPOSITION (%) AND CONDUCTIVITY[a]

Ion		Black Pond	Spitfire Lake	Lower St. Regis Lake
Cations				
Sodium	(Na^+)	17	11	15
Potassium	(K^+)	4	4	3
Magnesium	(Mg^{2+})	23	23	28
Calcium	(Ca^{2+})	55	60	51
Iron	(Fe^{2+})	1	2	3
Anions				
Chloride	(Cl^-)	13	10	11
Sulfate	(SO_4^{2-})	40	29	24
Bicarbonate	(HCO_3^-)	47	61	65
Conductivity	($\mu S\ cm^{-1}$)	51	44	55

[a] Based on logarithmic mean values.

In the St. Regis lakes, as in other Adirondack lakes with significant populations, bicarbonate exceeds sulfate. In the upper lakes septic tank leachate may increase alkalinity slightly, and in the lower lake the apparent (but not statistically significant) increase in ionic content and alkalinity may be an effect of sewage additions. This contribution is not affected by sewage treatment and will continue; it is generally beneficial, as it tends to neutralize the natural acidity.

Iron

The total iron concentrations in the epilimnion and hypolimnion of Lower and Upper St. Regis lakes are given in Figs. 12 and 13. Both lakes show

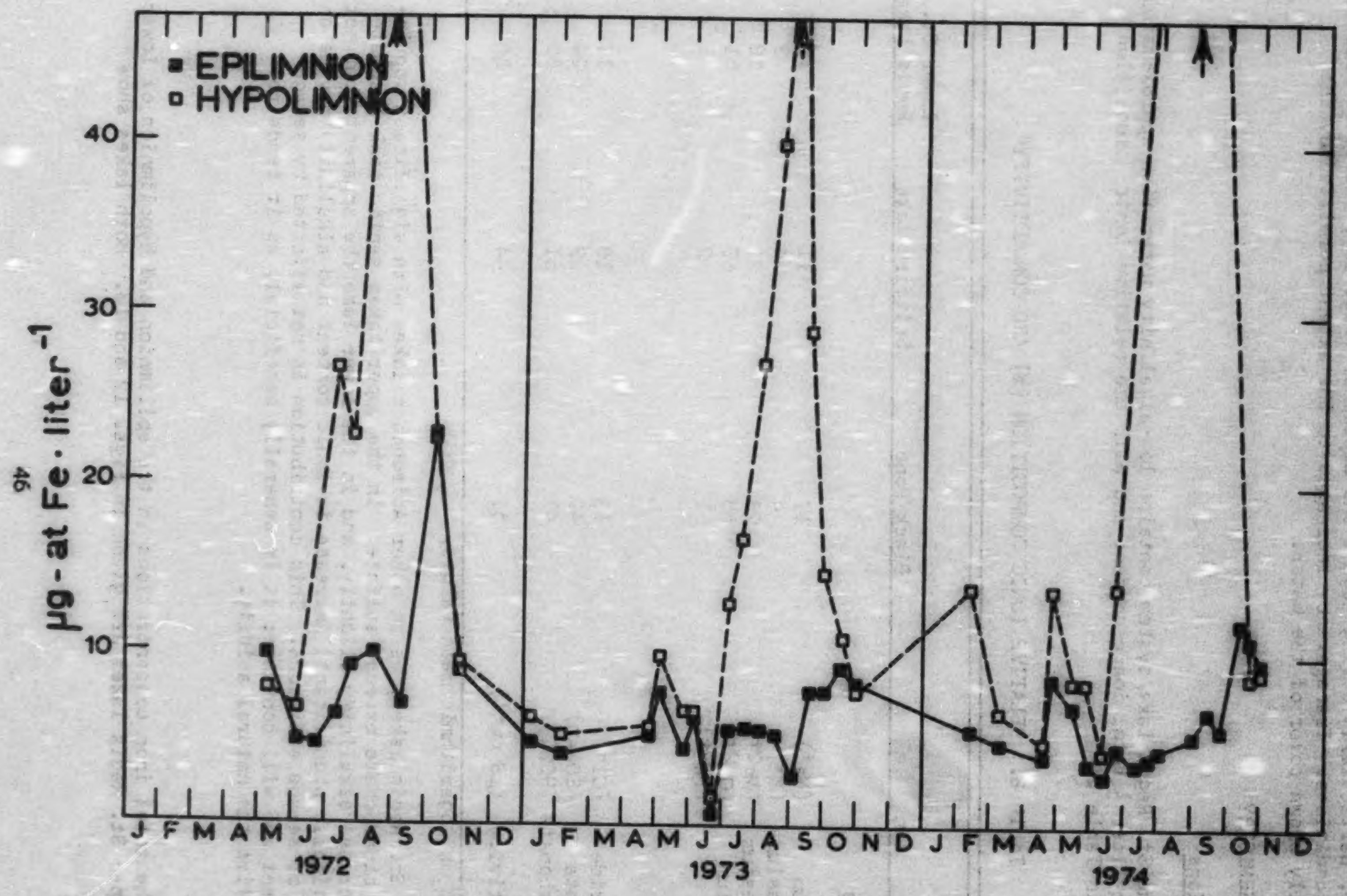

Fig. 12. Total iron values for Lower St. Regis Lake, 1972-1974.

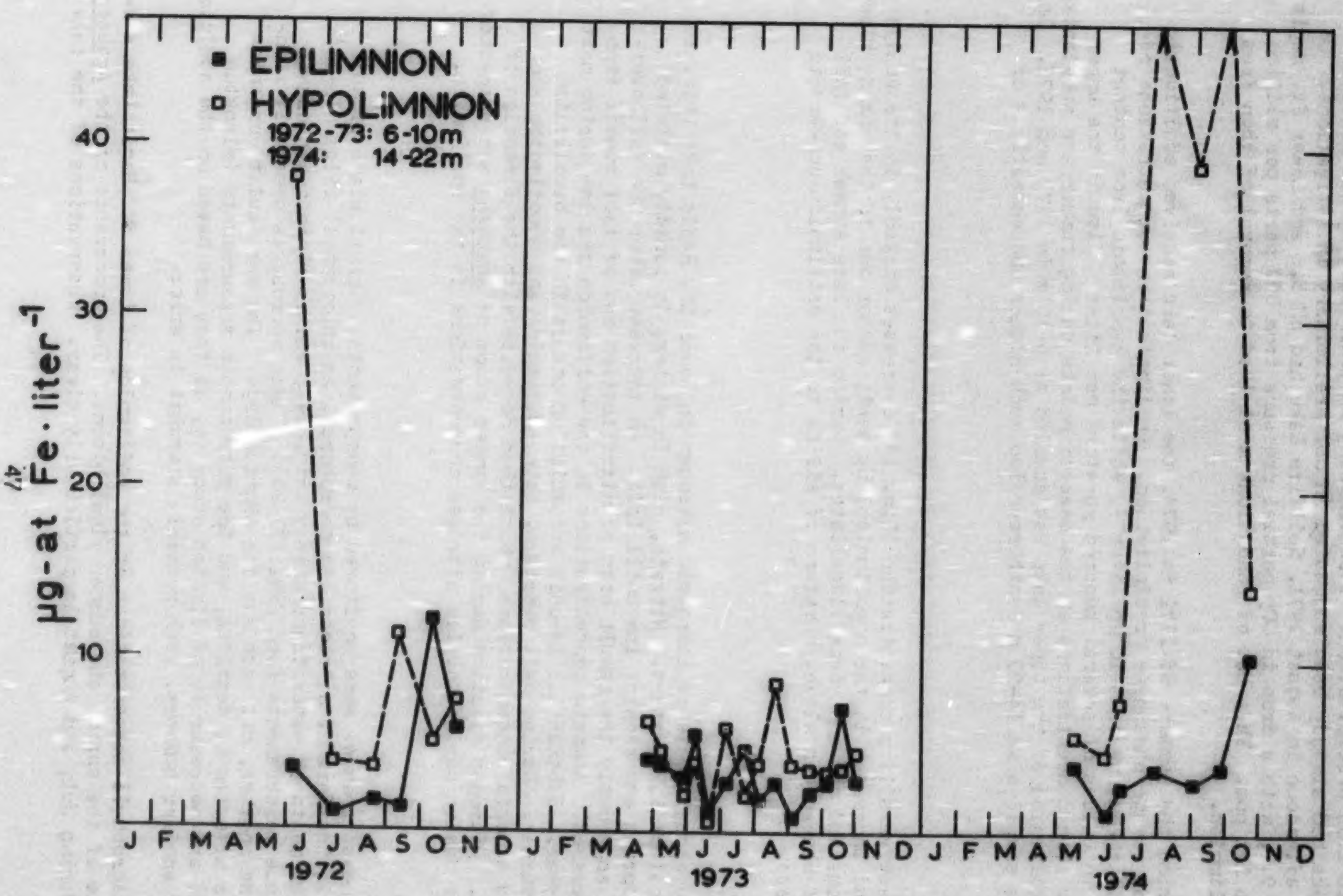

Fig. 13. Total iron values for Upper St. Regis Lake, 1972-1974.

epilimnic iron depletion during the growth season, but this is not entirely due to algal uptake, as increasing pH values under the effect of photosynthesis result in iron precipitation. Iron trapping in years past by the polluted lower lake had already been suggested in our preliminary investigations. On a sunny afternoon in August 1971, Spitfire Lake had pH 5.8 and Lower St. Regis Lake pH 9.5, with a drop in CO_2 partial pressure from 500 parts per million (ppm) to 125 ppm. This set of conditions must lead to removal of iron from the epilimnion.

During the summers of 1972 to 1974, the lower lake received additional iron from sewage phosphate precipitation. Epilimnic iron concentrations remained in the range of 5-10 μg $liter^{-1}$, while the hypolimnic iron content climbed to values of several hundred μg-atoms per liter. Also in the upper lake the iron concentrations at the deepest points during summer are substantial. (The hypolimnion of the upper lake was sampled at 6-10 m in 1972 and 1973. In 1974 the sampling at 14-22 m depth revealed much higher concentrations of iron.)

Silicon

Reactive silica concentration (Fig. 14) decreases markedly in the epilimnion (and increases in the hypolimnion) by early summer due to the spring bloom of diatoms and chrysophycean flagellates. During the late summer and fall bloom of blue-green algae, a return of silica to the epilimnion appears to take place.

Nitrogen

The annual cycle of inorganic nitrogen in Lower St. Regis Lake (Fig. 15) is typical of lake waters. Nitrate, high in winter, is rapidly depleted during spring and remains low until fall. An increase after the fall overturn is apparently the result both of nitrification and of fall runoff from the watershed. Ammonia concentrations in the epilimnion are low during most of the year. Substantial ammonia accumulation occurs in the hypolimnion during summer. During fall overturn, both epilimnion and hypolimnion show elevated ammonia concentrations, which then decrease with the formation of nitrate. Nitrogen fixation during the summer bloom of *Anabaena* was suspected to occur during periods of low nitrogen concentrations in the epilimnion.

BIOMASS

Biomass changes were monitored by measurements of particulate organic matter in the form of nitrogen and phosphorus, as chlorophyll (Figs. 16-18), by measurements of water transparency (Fig. 19), and as microscopic counts and volume measurements (see Figs. 20-23). These approaches generally reinforce one another, but each has its shortcomings. The particulate organics data are affected by detritus, and the microscopic measurements (plankton volumes) are necessarily of limited accuracy, as they are based on the addition of many smaller numbers, each possibly somewhat in error.

Chlorophyll concentrations in the epilimnion of Lower St. Regis Lake show evidence of the spring and summer algal blooms. The appearance of the *Anabaena* bloom during July and August is particularly clear. Observations of the lake

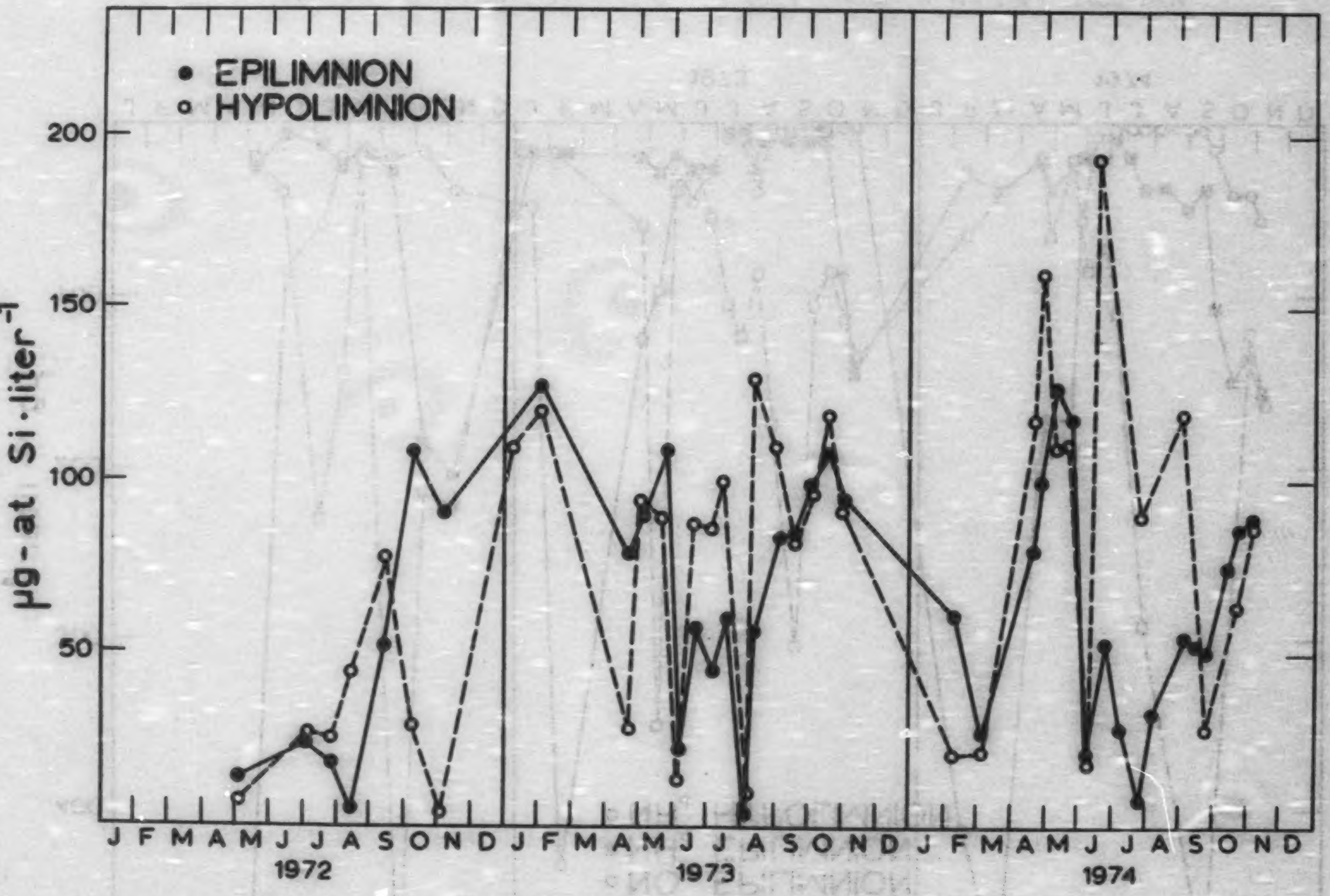

Fig. 14. Reactive silica values for Lower St. Regis Lake, 1972-1974.

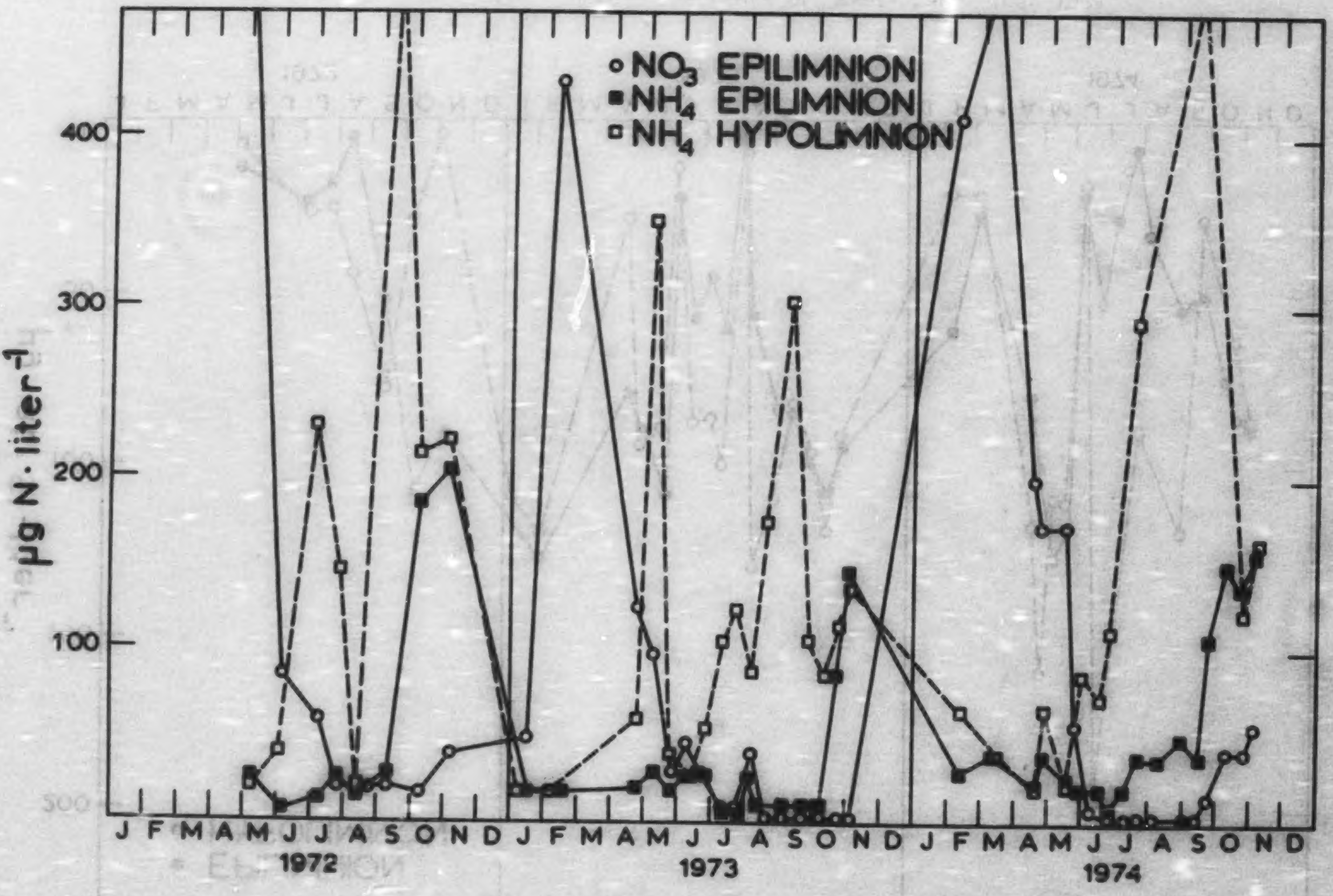

Fig. 15. Inorganic nitrogen values for Lower St. Regis Lake, 1972-1974.

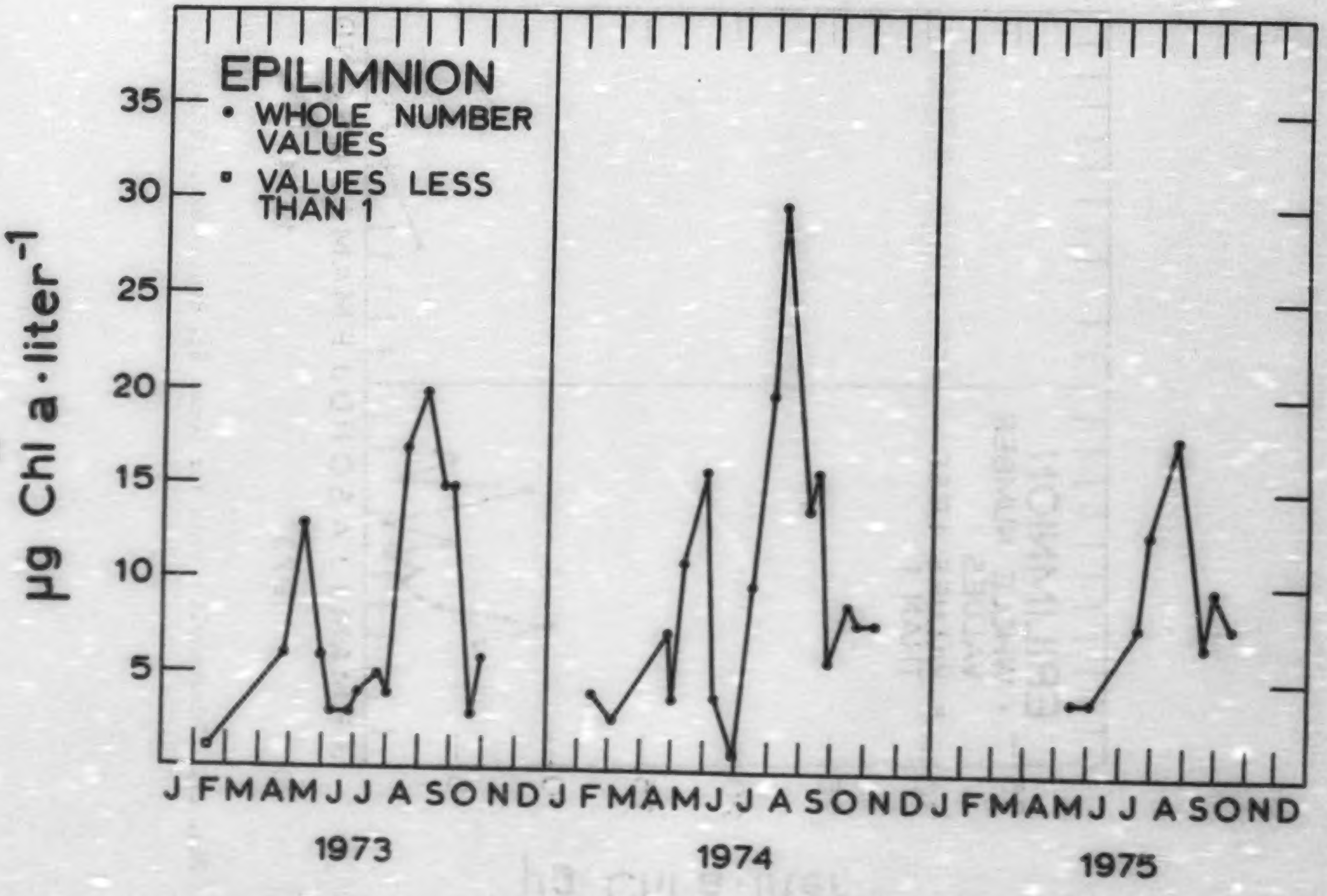

Fig. 16. Chlorophyll a data for Lower St. Regis Lake, 1973-1975.

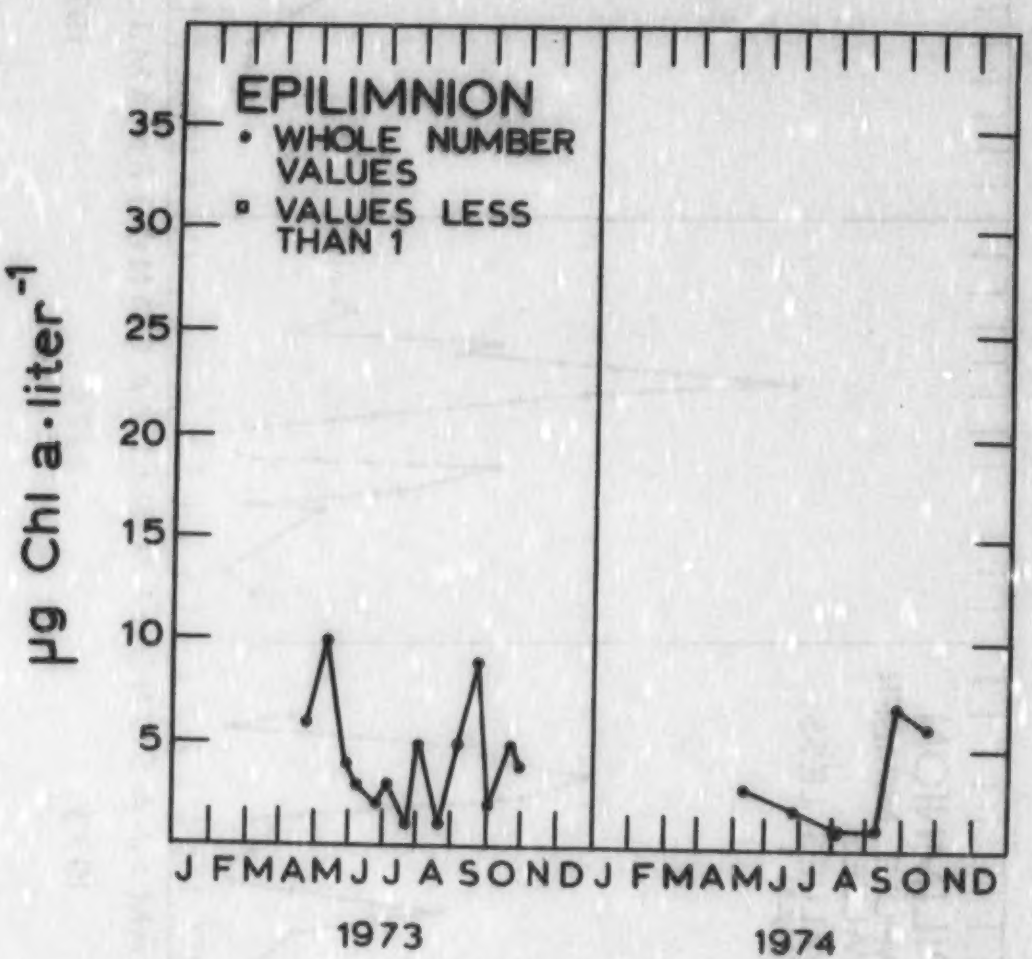

Fig. 17. Chlorophyll a data for Upper St. Regis Lake, 1973-1974.

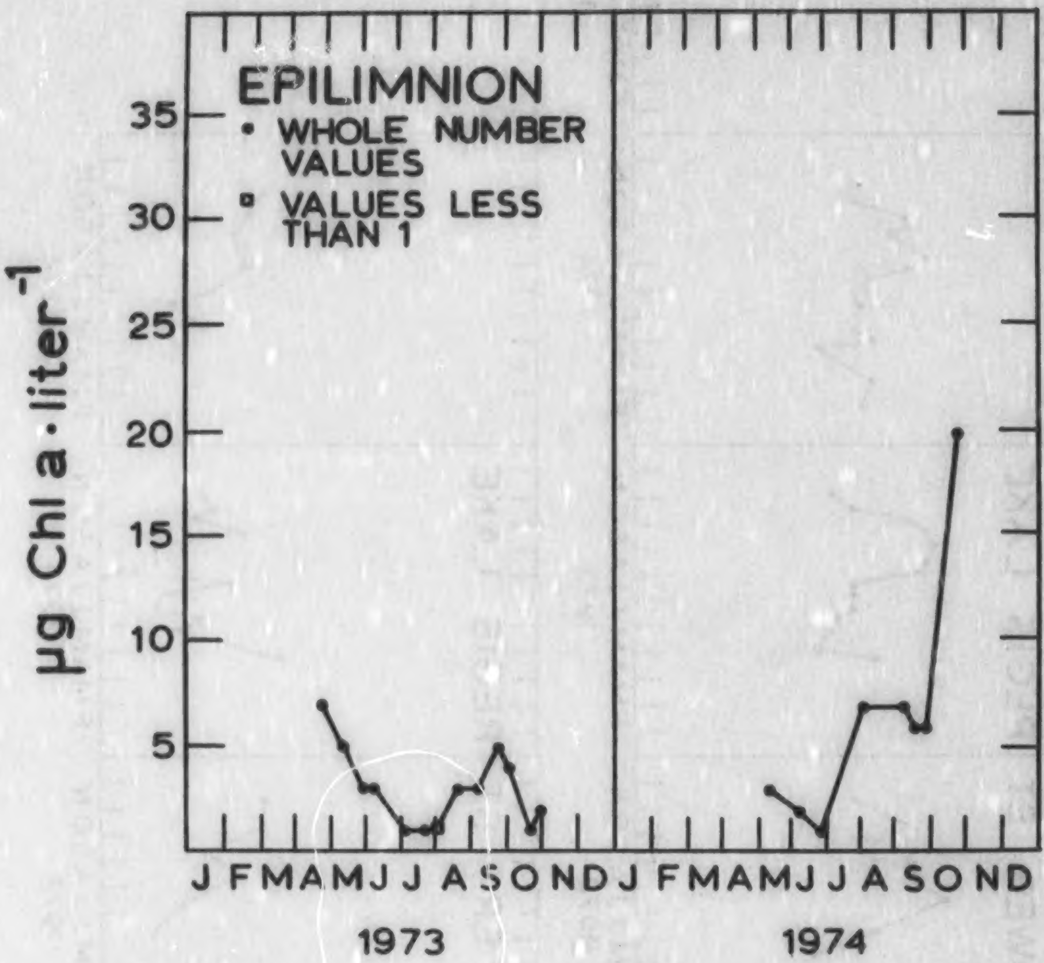

Fig. 18. Chlorophyll a data for Spitfire Lake, 1973-1974.

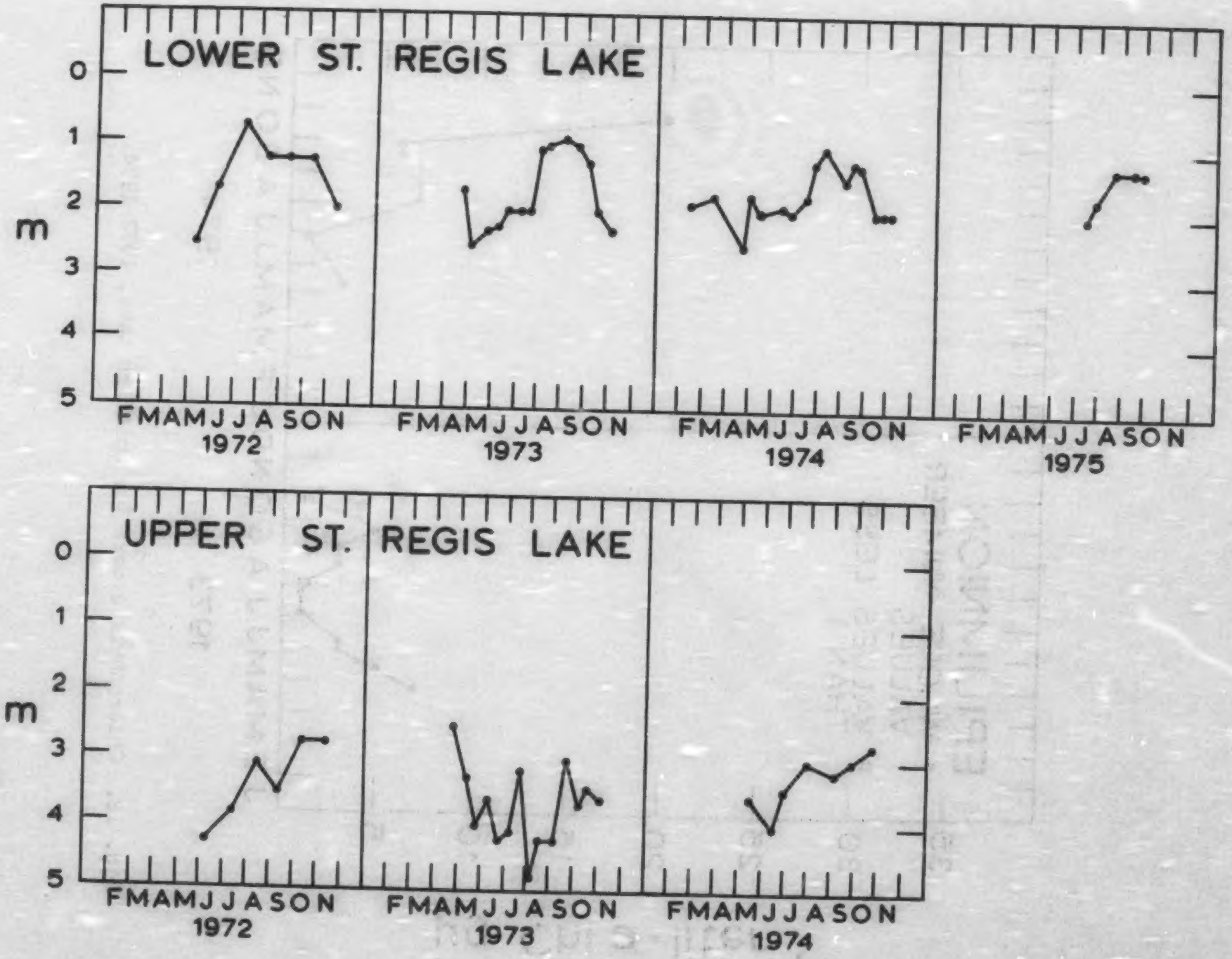

Fig. 19. Secchi disc transparencies for Lower St. Regis and Upper St. Regis Lakes, 1972-1975.

surface indicated delays of about two weeks per year in the appearance of the Anabaena bloom over the period 1972-74. The epilimnion composite samples for microscopic analysis confirm this (see plankton results, Figs. 20-23).

The underwater light measurements reveal the movement of an absorption maximum, particularly in the red region, toward the lake surface. In 1973 a maximum had reached the 1-2 m layer on July 19 and the surface by August 1. In 1974 it was at 1-2 m depth until July 30 but reached the surface by September 4. (Unfortunately, no measurements were taken on the August 8 survey date.) The measurements also reveal a surface maximum on July 12, 1972, denser than the 1973 and 1974 August maxima.

In 1975, one year after complete and year-round elimination of the phosphorus point source, a spring bloom of diatoms and flagellates was absent for the first time, as expressed in chlorophyll, transparency, and microscopic measurements, and the summer bloom was drastically reduced in both extent and duration. The latter observation suggests that the summer blooms are nourished to some extent by nutrients deposited during and remobilized after the spring bloom.

SEDIMENT ANALYSIS

General Characteristics

The sediments in most parts of Lower St. Regis Lake were mucky, deep brown, and softer than the sediments in Spitfire Lake. Near the outfall of Paul Smith's College sewage treatment plant into the mouth of Easy Street Creek, banks of black mud had accumulated over the years, but within a short distance from the mouth the lake sediments were quite firm and sandy.

The odor of hydrogen sulfide was never detectable, but it is likely that hydrated ferrous sulfides were present. The iron content of the sediments was high, and a slight sulfate depletion of the hypolimnion in summer was indicated.

On August 25, 1967, a sediment sample at 7-m (23-ft) depth was taken with an Ekman dredge by Dr. Carl Schofield of the Department of Natural Resources, Cornell University. Some of his results are given in Table 9 with permission, and his results from a sample from the same depth in Upper St. Regis Lake are shown as a comparison. Several extractable fractions of phosphorus and of cations were also determined.

Table 9. SEDIMENT ANALYSIS RESULTS

Constituent	Lower Lake	Upper Lake
Water content (%)	92.1	91.2
Organic content (% of dry weight)	40.9	41.4
Total phosphorus (% of dry weight)	0.1405	0.1334
Organic phosphorus (% of dry weight)	0.794	0.750

The sediment observations in Tables 10 and 11 are from our August 5, 1971, survey (New York State Dept. of Health, 1972) using an Ekman dredge. The sediments showed considerable variation in organics content in close relation to their sandy or mucky appearance. The sediment from the littoral near the college library (B3) was essentially an iron phosphate-hydroxide. The deep sediments (B4-B6) were fluffy, mucky, and high in organic content. The highest organic content was found near an abandoned sawmill, where a large dump for tree bark still existed. The sample from Spitfire Lake outlet was substantially lower in phosphate than the samples from the lower lake.

The Ca to P atomic ratios showed that there was more phosphorus in the sediments than the calcium could absorb. The Fe to P ratios indicated that there was more iron in the sediments than there was phosphorus with which to combine.

Sediment Core Analysis

A sediment core was taken at station 174 in Lower St. Regis Lake on March 8, 1974, and was sealed at the lake for immediate transport to the laboratory. There the flocculent sediment was stored in a cold room (4°C) for 1 week to allow compaction to take place. The core was then fractionated, and each segment was stored in a polyethylene bag and frozen until analysis. At the time of analysis the thawed samples were air-dried, homogenized, and passed through a 20-mesh sieve. The chemical determinations were performed by the Analytical Chemistry Laboratories of the Environmental Health Center. Metals were measured by atomic absorption spectrometry after extraction with nitric acid and distilled water (1:1).

The results (Table 12) gave no indications of bonds or laminations in the core which could be used to establish a chronology of cultural activity within the basin. Organic carbon content of the sediment decreased slightly with increasing distance from the sediment water interface. The relatively small variations in the abundance of organic carbon in the sediment indicate that the factors which regulate its abundance have remained in balance during the period encompassed by the sediment core. Insufficient data were available to give a clear description of the variation of organic nitrogen (Kjeldahl) with sediment depth.

The phosphorus content was highest adjacent to the mud-water interface and decreased with increasing sediment depth. In contrast, the content of metals in the sediment remained relatively constant throughout the core. This indicates that the phosphorus-adsorptive capacity of the sediment was constant throughout. The higher phosphorus content in the surficial sediment reflects an increase in the supply of phosphorus to Lower St. Regis Lake in the recent past and/or an increase in the efficiency of phosphorus sedimentation. Methane formation in the upper strata of the sediment may have contributed to its mixing (see p. 61).

Table 10. DESCRIPTION OF SAMPLING SITES AND CONSISTENCY OF BOTTOM SEDIMENTS

Sampling site		Sediment consistency
Lower St. Regis Lake		
B_1	1-m depth near mouth of Easy Street Creek, which receives effluent from Paul Smith's College sewage treatment plant	Sandy
B_2	2-m depth, further into lake body in line with Easy Street Creek	Sandy
B_3	2-m depth in front of college library	Rather mucky
B_4	5-m depth near mouth of tributary from Barnum Pond, near old sawmill and tree bark dump	Mucky (black)
B_5	4-m depth at beginning of lake outlet arm	Mucky
B_6	9-m depth midway between mouth of Easy Street Creek and channel from Spitfire Lake	Mucky
Spitfire Lake		
B_7	4-m depth at northeast end of lake prior to beginning of the channel	Sandy

Table 11. BOTTOM SEDIMENT SAMPLES

	Chemical analyses (mg g^{-1} dry weight)[a]						Atomic ratios				
Sampling site	Carbon (C)	Nitrogen (N)	Phosphorus (P)	Calcium (Ca)	Iron (Fe)	Manganese (Mn)	$\frac{C}{N}$	$\frac{C}{P}$	$\frac{N}{P}$	$\frac{Ca}{P}$	$\frac{Fe}{P}$
B_1	8.0	0.5	4.2	1.1	69	1.6	18.7	4.9	0.3	0.20	9.0
B_2	5.2	0.5	0.30	0.093	3.55	0.43	12.1	44.8	3.7	0.24	6.5
B_3	11	1.0	36.7	2.1	820	2.2	12.8	0.8	0.1	0.04	12.4
B_4	450	19.6	2.73	0.35	64.7	0.69	26.8	425.1	15.9	0.10	13.1
B_5	240	24.2	2.2	0.46	125	0.74	11.6	283.6	24.5	0.16	31.6
B_6	290	44.7	5.3	0.8	146	1.3	8.1	183.0	26.4	0.12	16.7
B_7	19	1.0	0.4	0.088	18.5	0.13	22.2	136.7	6.2	0.19	28.5

[a] milligram per gram.

Table 12. CHEMICAL STRATIGRAPHY (%) OF A SEDIMENT CORE FROM LOWER ST. REGIS LAKE

Constituent	Mean distance of sediment section from sediment water interface (cm) 2.5	7.5	12.5	17.5	22.5	27.5	32.5
Dry solids	3.9	4.3	4.6	4.6	4.6	5.8	8.7
Total carbon	41.5	38.5	45.0	41.5	38.5	36.5	33.5
Organic carbon	40.0	36.5	35.0	38.5	38.5	36.5	33.5
Nitrogen (Kjeldahl)	-	1.8	0.96	1.7	-	-	-
Total phosphorus	0.14	0.14	0.10	0.09	0.07	0.08	0.05
Iron	5.6	6.0	5.8	5.5	4.8	4.9	5.5
Manganese	0.071	0.063	0.059	0.048	0.042	0.036	0.035
Calcium	0.35	0.29	0.34	0.38	0.38	0.39	0.38
Zinc	0.02	0.016	0.015	0.022	0.017	0.005	<0.005

Phosphate Release from Sediments

As part of our 1971 survey (New York State Department of Health, 1972), an initial experiment was performed in which sediment samples were collected with an Ekman dredge, transferred to cylindrical vessels and kept at room temperature for 3 weeks. The results are shown in Table 13.

Table 13. REACTIVE PHOSPHATE RELEASE FROM BOTTOM SEDIMENT AFTER 21-DAY INCUBATION (μg P liter^{-1})

Sampling Site	Aerobic conditions	Anaerobic conditions
B_1	28.6	97.6
B_2	17.0	21.6
B_3	23.6	10.8
B_4	41.0	22.0
B_5	45.6	52.0
B_6	38.6	457.4
B_7	14.0	6.4

On November 6, 1974, samples were obtained by coring somewhat shoreward from the main sampling station located at the deepest point of the lake. This choice of location was necessary due to the presence of almost 50 cm of "fluffy" unconsolidated sediments at the main station and the requirement that the sediments comprise only about half the volume of the core tube. Six subsamples of the incubated core sample were taken on November 14, 1974, and the tubes were incubated in the dark at room temperature for 4 more weeks. Three tubes selected at random were made anaerobic by sparging them with nitrogen gas and sealing them with No. 11 rubber stoppers. The other three tubes were kept aerobic. The changes in reactive phosphate and in total soluble phosphate during the incubation period were measured (Table 14).

All tubes showed an increase in reactive phosphorus (P react.) and total soluble phosphorus (P total sol.) in the water at the end of the incubation period (28 days). Tube 3 had more P react. than P total sol., which caused us to suspect the presence of substances interfering with phosphate analyses. High variability was also found among the other anaerobic systems. Consequently, though P react. increased by 2.82 micrograms per day (µg day^{-1}), the standard deviation (SD) of ± 2.03 indicates that the results are of questionable significance. Similar results were obtained for P total sol. (2.68 ± 2.19 µg day^{-1}) in the water column. Increases under aerobic conditions were much more uniform: 1.61 ± 0.40 and 1.90 ± 0.15 µg day^{-1} for P react. and P total sol. respectively. In either case, soluble phosphate is released to the water column from both aerobic and anaerobic systems in the dark at room temperature.

Table 14. SOLUBLE PHOSPHATE RELEASE FROM SEDIMENT CORE AFTER 28-DAY INCUBATION (µg P liter^{-1})

		P react.		P total sol.	
Tube	Treatment	Initial	Final	Initial	Final
1	Anaerobic	6.7	27.8	15.7	35.3
2	Anaerobic	9.3	144.0	20.6	162.0
3	Anaerobic	28.3	110.0	45.5	34.7
4	Aerobic	4.0	60.7	15.9	73.7
5	Aerobic	16.7	50.3	26.6	75.7
6	Aerobic	8.9	54.1	26.2	79.6

P react. = reactive phosphorus
P total sol. = total soluble phosphorus

Prior to analysis the samples contained a considerable amount of filterable orangish precipitate, even though they had been filtered before being stored frozen. This precipitate was found in both aerobic and anaerobic samples. The highly variable results obtained from the anaerobic tubes suggest a variable interference with the phosphate determinations. Evidence of interfering substances comes from sediment determinations using aerobic surface sediments and deeper sediments in the same core corresponding to the region of maximum gas retention (about 20 cm below the mud-water interface). To investigate anaerobic sediments the surfaces of cores with an anaerobic water column and mud from about 20-cm depth in the anaerobic tubes were analyzed. In these anaerobic samples P react. generally exceeded P total sol. The mean of the nine P react. values was 685.9 µg liter^{-1} (SD ± 475.84); that for P total sol. was 598.09 (SD ± 405.81). For aerobic samples P total sol. (37.19 ± 23.22) exceeded P react. (32.77 ± 35.28). The high variance for P react. was due to one inversion (P react. > P total sol.) in the set of nine values. This comparison indicates that P total sol. determinations may be subject to analytical error due to oxygenation of the anaerobic samples during processing.

In all tubes a region varying between 52 and 107 mm in thickness and 13 and 20 mm in depth below the mud-water interface contained many bubbles of gas. These escaped periodically prior to sampling at the end of the experiment. Gas formation and release is a likely mechanism for the transport of phosphates and reducing substances into the water column, and methane oxidation is probably a factor contributing to the hypolimnic oxygen depletion in this lake.

PLANKTON

A summary of the range of total plankton biomass encountered on the three lakes from 1972-1975 is found on Table 15. "Total" plankton refers to the predominant species which were quantified.

Lower St. Regis Lake

Anabaena Species Biomass 1972-1975--

Figures 20-23, which illustrate the dynamics of the epilimnic *Anabaena* species populations in terms of total plankton biomass, show clearly the decline over the years in the productivity of these blue-green algae. *Anabaena* spp. comprised the bulk of the epilimnic biomass. *Anabaena scheremetievi* Elenkin was the predominant species; other species included *A. circinalis* var. *macrospora* (Wittr.) DeToni, *A. wisconsinense* Prescott, *A. affinis* Lemmermann, *A. flos-aquae* (Lyngb.) De Brébisson, and possibly *A. levanderi* Lemmermann.

In 1972 *Anabaena* spp. passed the 10 mm^3 liter^{-1} mark in mid-July (7/18) and remained above this level essentially through early October (10/4), peaking at 22 mm^3 liter^{-1} in late September (9/26). The *Anabaena* biomass average during this period was 15 mm^3 liter^{-1}.

In 1973 *Anabaena* spp. reached the 10 mm^3 liter^{-1} mark 2 weeks later, in early August (8/2), and remained at this level essentially through early October (10/4), peaking at 15 mm^3 liter^{-1} in early September (9/4). The *Anabaena* biomass average during this period was 11 mm^3 liter^{-1}.

In 1974 *Anabaena* spp. passed the 10 mm^3 liter^{-1} level in late August (8/26) with a peak of 15 mm^3 liter^{-1} and again early in September (9/4) at 11 mm^3 liter^{-1}. From August 8 through September 13 the *Anabaena* biomass average was 8.5 mm^3 liter^{-1}.

In 1975 *Anabaena* spp. did not reach the 10 mm^3 liter^{-1} level at all. The highest volume, 8.9 mm^3 liter^{-1}, was recorded on August 21. The *Anabaena* biomass average from July 17 through September 17 was 5.6 mm^3 liter^{-1}.

As of the earliest sampling date in July during 1972-1975, the *Anabaena*

Table 15. TOTAL PLANKTON BIOMASS RANGE
(mm^3 $liter^{-1}$)

Lake	Year	Winter	Spring	Summer	Fall
Epilimnion					
Lower St. Regis	1972		1.3-3.9	3.0-20.	3.3-32.
	1973	<0.10	<0.10-14	2.0-17.	6.5-26.
	1974	<0.10	<1.0-2.9	1.8-34.	1.4-13.
	1975	<0.10	<1.0	1.5-11.	1.2-10.
Upper St. Regis	1972			3.7-32.	<1.0-2.2
	1973		<1.0-10	1.1-17.	<1.0-2.2
	1974		<1.0	<1.0	<1.0-2.9
Spitfire	1973		1.0-11.	<1.0-3.1	<1.0-5.4
	1974		3.0	<1.0	<1.0-2.8
Hypolimnion					
Lower St. Regis	1972		<0.10-2.2	<0.10-1.0	<0.10-13.
	1973	<0.10	<0.10-4.7	<1.0-23.	<1.0-3.7
	1974	<0.10-4.1	<0.10-1.0	<0.10-7.8	<0.10-5.6
	1975	<0.10	1.2	<0.10-1.3	<1.0-1.6
Upper St. Regis	1972			2.6-7.4	<1.0-2.7
	1973		<1.0-3.4	<1.0-10.	<1.0-1.1
	1974		<1.0	<1.0	<1.0
Spitfire	1973				
	1974				

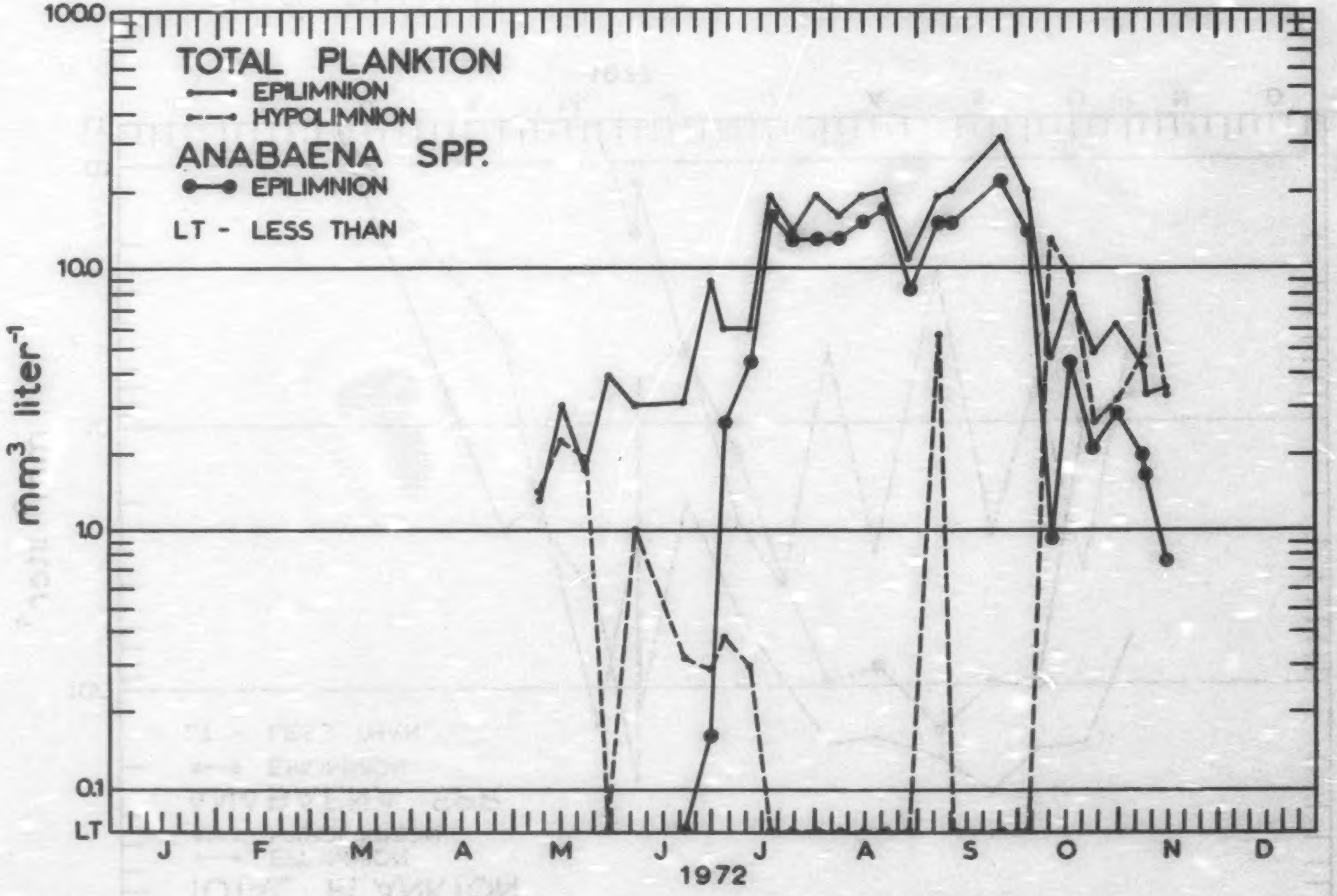

Fig. 20. Total plankton and *Anabaena* spp. biomass for Lower St. Regis Lake, 1972.

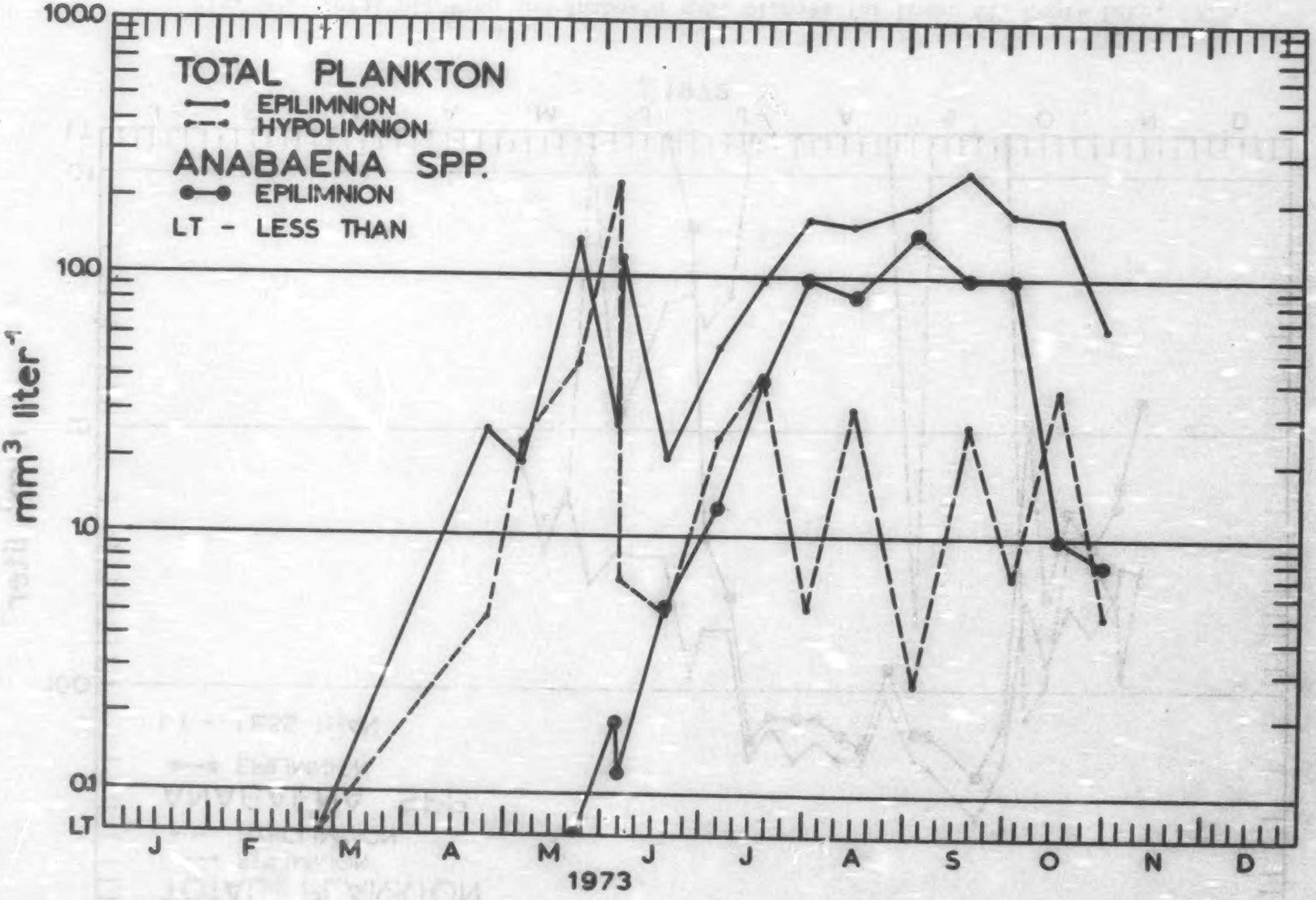

Fig. 21. Total plankton and *Anabaena* spp. biomass for Lower St. Regis Lake, 1973.

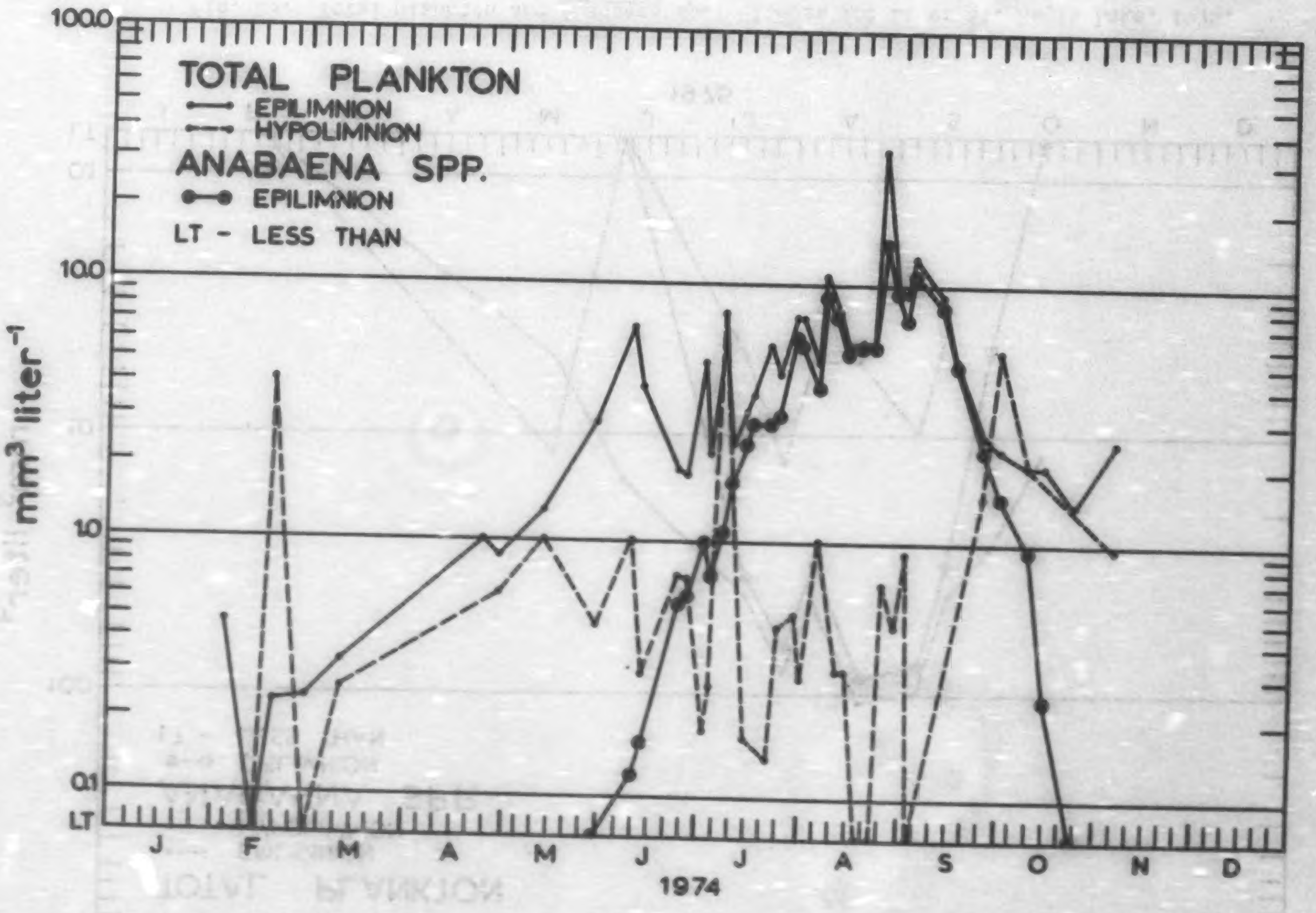

Fig. 2. Total plankton and Anabaena spp. biomass for Lower St. Regis Lake, 1974.

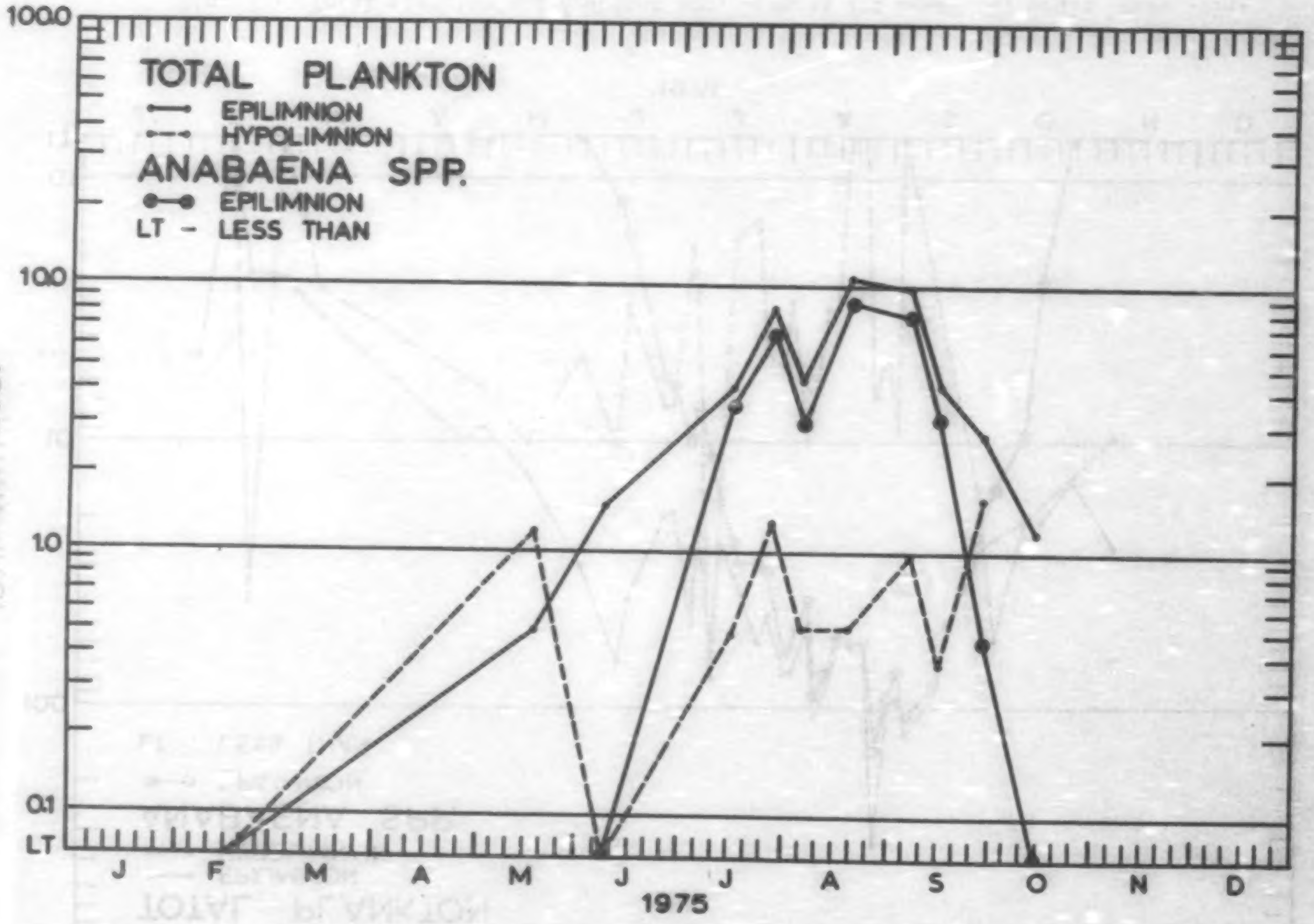

Fig. 23. Total plankton and *Anabaena* spp. biomass for Lower St. Regis Lake, 1975.

biomass was 1.0 mm^3 liter^{-1} or greater, but the biomass receded permanently below that level at an earlier date each year - in 1972, mid-November (11/15); in 1973 and 1974, mid-October (10/18 and 10/10); and in 1975, late September (9/30).

Predominant Plankton--

Figures 24-27 illustrate the epilimnic biomass pattern for the predominant plankton species for 1972-1975. Blue-green algae (Cyanophyta) comprised the bulk of this biomass during the summer and fall. The major species were Anabaena scheremetievi and Coelosphaerium naegelianum, but Anabaena circinalis var. macrospora was also often important in late summer and fall. Species which contributed significantly to the biomass during short periods of time were: Spring and/or early summer: Uroglenopsis americana, Dinobryon divergens, D. bavaricum, Asterionella formosa, Synura spp. (all Chrysophyta), Cryptomonas erosa (Pyrrhophyta), and Dictyosphaerium pulchellum (Chlorophyta). Summer: Fragilaria crotonensis (Chrysophyta) and ciliates (Ciliophora). Late summer and/or fall: Cryptomonas ovata (Pyrrhophyta), Melosira granulata (Chrysophyta), rotifer (Rotifera), Eudorina elegans, and Pandorina morum (Chlorophyta). In addition, M. granulata reached rather high concentrations (1.0 to 5.6 mm^3 liter^{-1}) in the hypolimnion during occasional periods throughout the whole sampling season.

Figures 20-23 illustrate the total biomass of predominant plankton (epilimnion and hypolimnion curves) for 1972-1975. The major observations for each year can be summarized as follows:

1972--During May the epilimnic plankton community consisted mainly of ciliates and of these flagellated forms: Synura uvella and S. adamsii (small bloom with a combined biomass of 1.5 mm^3 liter^{-1}), Dinobryon divergens, Cryptomonas erosa, C. ovata, an unidentified form (diam. 3.5 μ), and Trachelomonas spp. The Cryptomonas species showed low counts throughout most of the sampling season, occasionally peaking above 2.0 mm^3 liter^{-1}.

Anabaena scheremetievi appeared in trace amounts during June and reached 2.6 mm^3 liter^{-1} early in July. By mid-July 16 mm^3 liter^{-1} of Anabaena were present in the epilimnic waters, and the level remained high through early October, peaking at 22 mm^3 liter^{-1} late in September. The peak total epilimnic biomass of 32 mm^3 liter^{-1} occurred at that time.

Coelosphaerium naegelianum and Gomphosphaeria lacustris, colonial blue-greens, ranged between 1.1 and 4.5 mm^3 liter^{-1} from late June through late October and peaked at 7.1 mm^3 liter^{-1} late in September.

From mid-July through early October the dominant blue-greens, A. scheremetievi and Coelosphaerium/Gomphosphaeria, accounted for 86-100% of the total epilimnic plankton biomass, which ranged from 11 to 32 mm^3 liter^{-1}.

D. divergens reached a peak of 5.5 mm^3 liter^{-1} late in June and then essentially vanished from the epilimnion. At this time also a small bloom of the green alga Dictyosphaerium pulchellum was evident (1.5 mm^3 liter^{-1}), and a similar concentration of ciliates occurred early in July. Late in September the green algae Eudorina elegans and Pandorina morum evidenced a small bloom

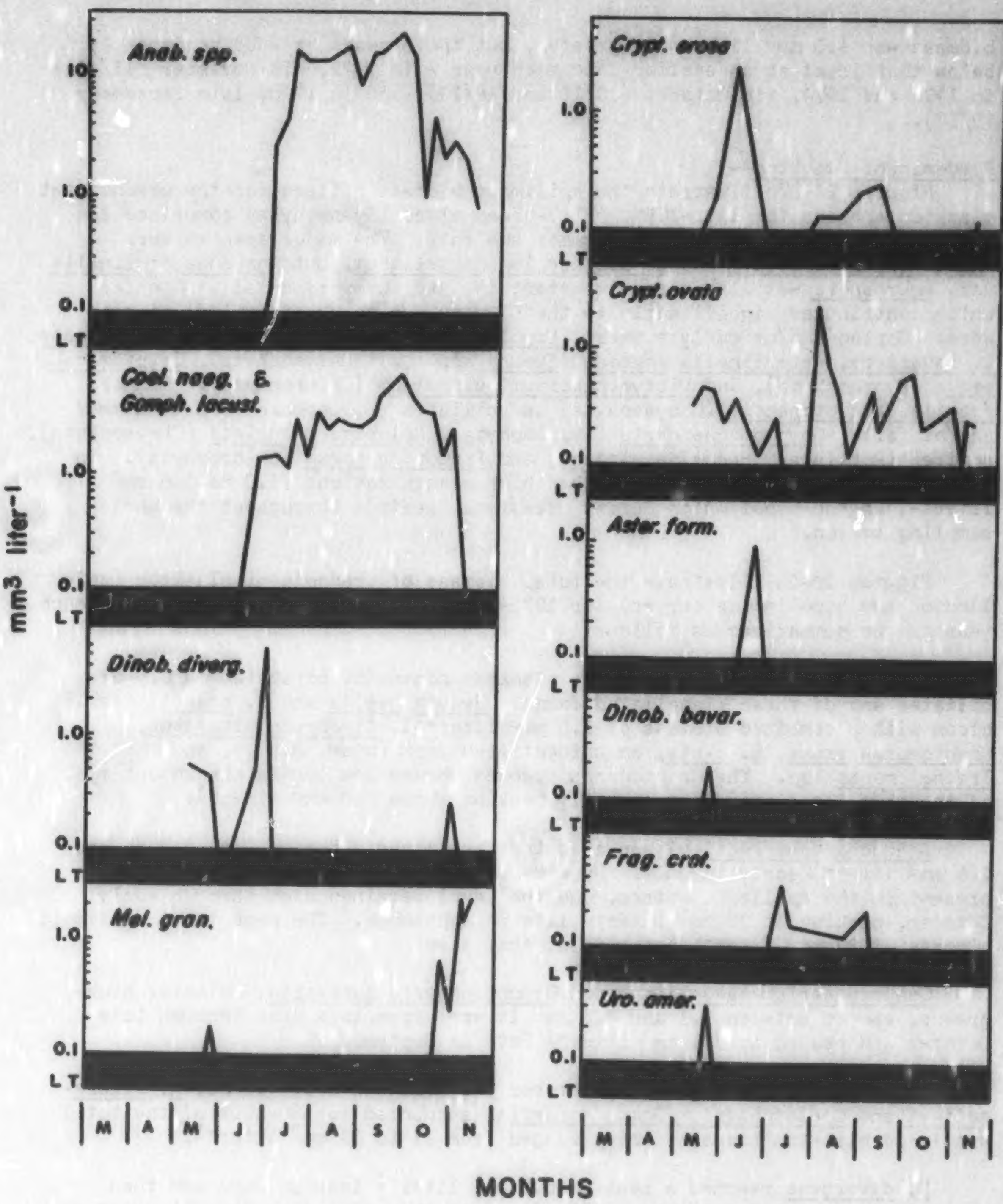

Fig. 24. Species biomass for Lower St. Regis Lake epilimnion, 1972.
LT = less than

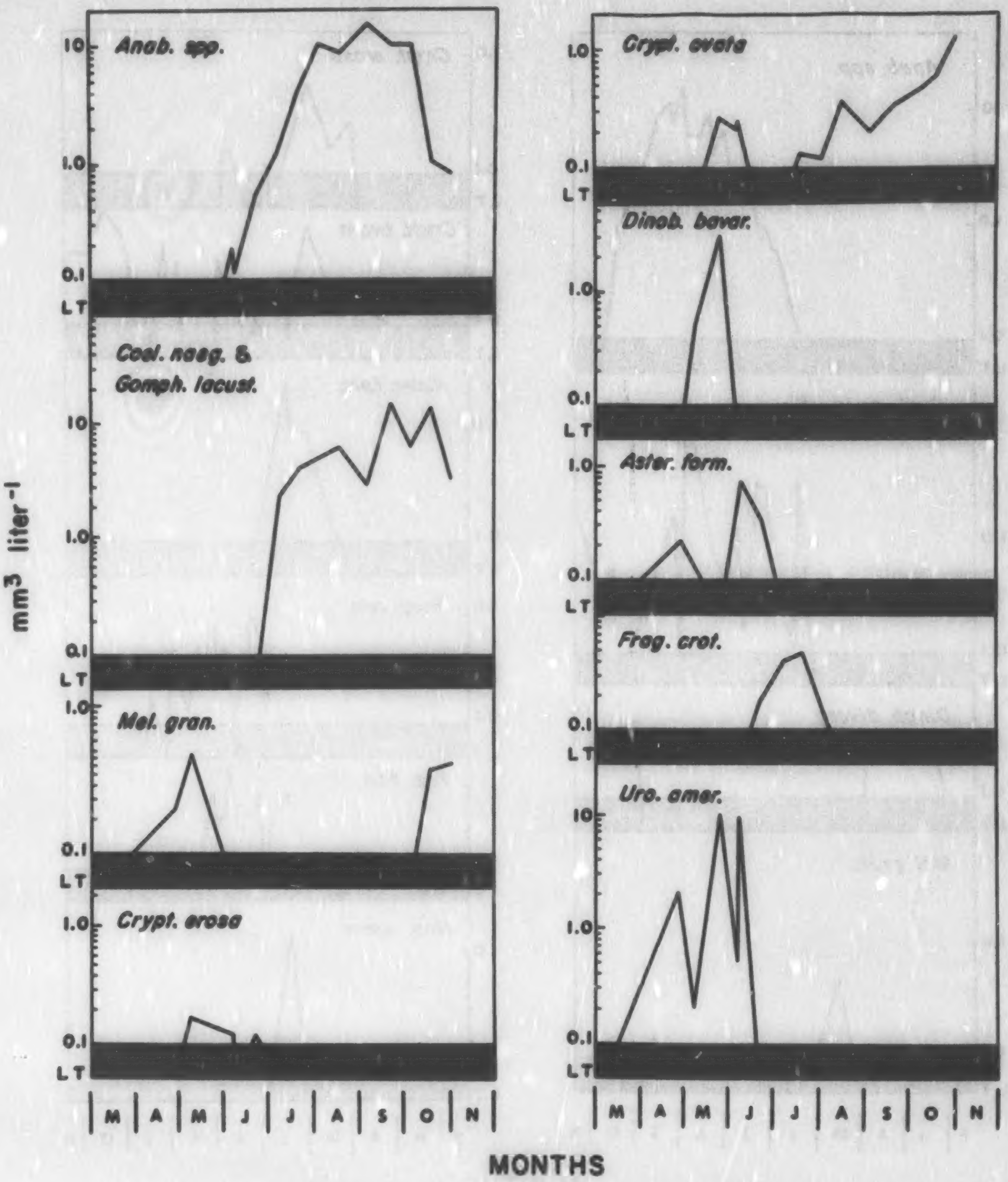

Fig. 25. Species biomass for Lower St. Regis Lake epilimnion, 1973.
LT = less than

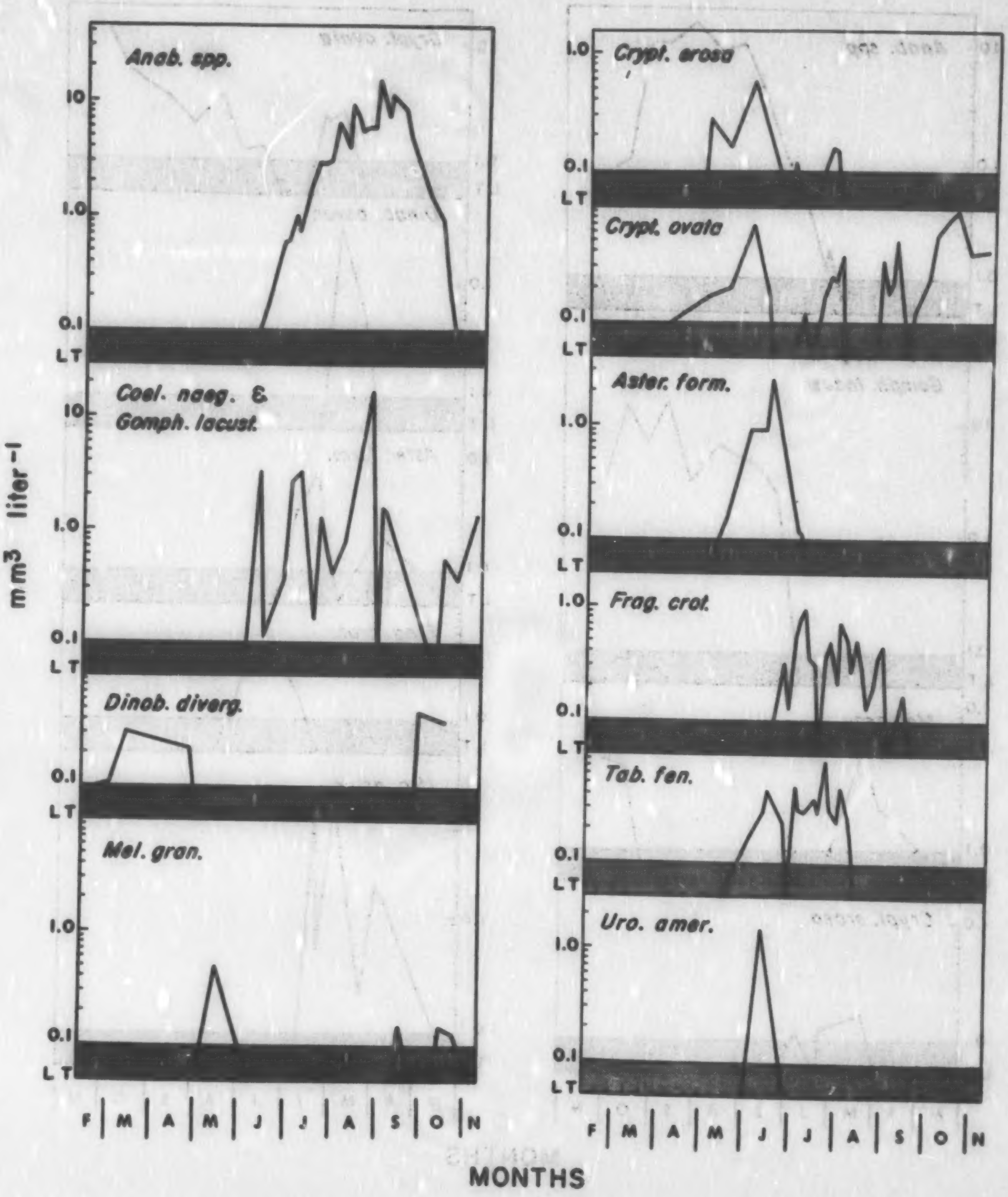

Fig. 26. Species biomass for Lower St. Regis Lake epilimnion, 1974.
LT = less than

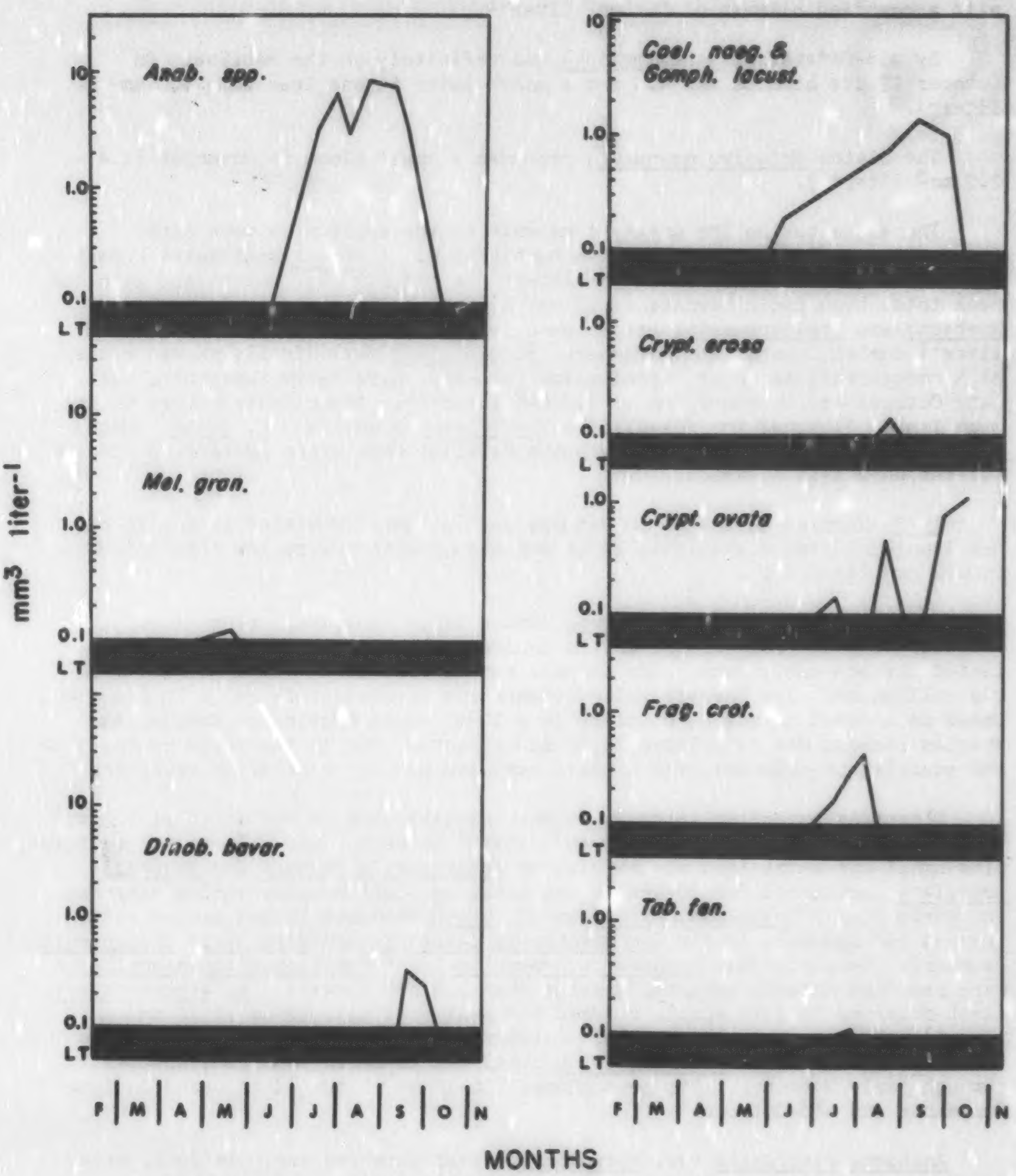

Fig. 27. Species biomass for Lower St. Regis Lake epilimnion, 1975.
LT = less than

with a combined biomass of 2.1 mm^3 liter^{-1}.

By mid-October *A. scheremetievi* was definitely on the decline. On October 17 its biomass was 4.4 and a month later it was less than 1.0 mm^3 liter^{-1}.

The diatom *Melosira granulata* produced a small bloom in November (1.4 - 2.2 mm^3 liter^{-1}).

The algae having the greatest biomass in the epilimnion were also the species most in evidence in the hypolimnion. *Anabaena* manifested a peak hypolimnic concentration of 12 mm^3 liter^{-1} in mid-October, coincident with the peak total hypolimnic biomass of 13 mm^3 liter^{-1}. Aside from this peak, *Anabaena* and *Coelosphaerium* each showed concentrations ranging up to 5.2 mm^3 liter^{-1} during October and November. *M. granulata* periodically showed rather high concentrations in the hypolimnion (mid-May, 2.2; early September, 5.6; late October and November, up to 3.7 mm^3 liter^{-1}). Minor contributors to the hypolimnion included the flagellates *Trachelomonas* spp. and *C. ovata*. High concentrations of mineral and amorphous detritus were often present. Actinomycetes were also observed.

1973--Samples collected in January and February consisted primarily of small unidentified flagellates (4 to 8-μ diam.) with a very low total biomass (<0.10 mm^3 liter^{-1}).

In April *Uroglenopsis americana* (whose large spherical colonies of flagellated cells are visible to the unaided eye) developed a bloom, which lasted through early June. Its biomass ranged from <1.0 - 10 mm^3 liter^{-1} in the epilimnion. The largest colony viewed was approximately 355 μ in diameter. Based on a count of one such colony in a 10-ml concentration of sample, the species biomass was calculated as 10 mm^3 liter^{-1}. Due to the large colony size and scarcity of colonies, the biomass estimate was not considered reliable.

Dinobryon bavaricum appeared in May, peaking late in the month at 3.2 mm^3 liter^{-1}. *Synura* spp. reached 1.0 mm^3 liter^{-1} in early June. These chrysophytes, plus small concentrations of the diatoms *Asterionella formosa* and *Melosira granulata*, accounted for 80-96% of the total epilimic biomass during late May and early June. *Cryptomonas erosa* and *C. ovata* appeared in low concentrations (spring and summer), as did *Gomphosphaeria lacustris* and *Fragilaria crotonensis* (summer). By early July *Anabaena scheremetievi* and *Coelosphaerium naegelianum* were reaching notable amounts, greater than 1.0 mm^3 liter^{-1}. *A. scheremetievi*, first observed in late April, reached its peak epilimnic bloom of 12 mm^3 liter^{-1} early in September. By mid-October its biomass had declined to less than 1.0 mm^3 liter^{-1}. *Coelosphaerium* continued to be an important species through early November. Its peak blooms (15-16 mm^3 liter^{-1}) occurred in late September and mid-October.

Anabaena circinalis var. *macrospora*, first observed early in June, produced a notable biomass in the epilimnion during September and peaked at 3.3 mm^3 liter^{-1} in October.

M. granulata and *C. ovata* appeared in low concentrations in the fall, *Cryptomonas* showing a small bloom (1.3 mm^3 liter^{-1}) early in November.

From early August through mid-October the dominant blue-greens *A. scheremetievi*, *A. circinalis*, and *Coelosphaerium/Gomphosphaeria* represented from 91 to 98% of the total epilimnic plankton, which ranged from 16 to 26 mm^3 liter^{-1}. The peak total epilimnic biomass (26 mm^3 liter^{-1}) occurred late in September.

These dominant species did not contribute significantly to the hypolimnic biomass, as in 1972. *M. granulata* reached a peak of 1.7 mm^3 liter^{-1} in the hypolimnic waters in May. Its small bloom in the upper and lower waters during the fall of 1972 did not recur the following year. In May and early June the colonial blue-green *Anacystis incerta* (4.8 mm^3 liter^{-1}) and the colonial chrysophyte *U. americana* (3.5 and 18 mm^3 liter^{-1}) contributed significantly to the hypolimnion. *C. naegelianum* appeared in the lower waters at 1.9 - 3.1 mm^3 liter^{-1} during July and August. *A. scheremetievi* filaments peaked over 1.0 mm^3 liter^{-1} only once, late in September. During mid-October a rotifer species with a biomass of 1.7 mm^3 liter^{-1} was observed in the hypolimnic sample. High concentrations of mineral and filamentous detritus were often present. The iron bacterium *Leptothrix* was seen occasionally.

1974--Epilimnic samples collected from February through April contained low concentrations of the flagellated chrysophytes and dinoflagellates *Synura* sp., *Dinobryon divergens*, *Cryptomonas erosa*, *C. ovata*, and *Peridinium* sp., plus unidentified flagellated and nonflagellated forms (3-7-μ diam.).

Combinations of four diatoms were found in low concentrations in the epilimnion between May and mid-September: *Melosira granulata*, *Asterionella formosa*, *Tabellaria fenestrata*, and *Fragilaria crotonensis*. In mid-June there was a small bloom of *Asterionella* (2.6 mm^3 liter^{-1}) and *Uroglenopsis americana* (1.5 mm^3 liter^{-1}). *Fragilaria* attained a small bloom early in July (1.0 mm^3 liter^{-1}).

Cryptomonas spp. maintained low concentrations throughout the sampling season. *C. ovata* reached near-bloom conditions in mid-October.

Anabaena scheremetievi was first observed late in May. By early July its concentration in the epilimnion was becoming notable (1.0 mm^3 liter^{-1}), and from July 2 through August 6 its average biomass was 2.6 mm^3 liter^{-1}. *A. scheremetievi* peaked late in August (13 mm^3 liter^{-1}) and began to decline in mid-September. Its average biomass was: August 8-September 13, 7.5 mm^3 liter^{-1}; September 17-October 24, 1.2 mm^3 liter^{-1}.

Anabaena circinalis var. *macrospora* was first observed in the epilimnion late in June. Concentrations remained low through the sampling season, peaking between 1.0 and 1.8 mm^3 liter^{-1} from late August to mid-September.

Coelosphaerium naegelianum contributed significantly to the epilimnion plankton biomass between June and November, reaching its peak in August. Its greatest biomass between June 10 and August 23 was 3.4 mm^3 liter^{-1}; August 26, 18 mm^3 liter^{-1}; August 30-November 6, 1.6 mm^3 liter^{-1}.

From August 8 through September 13 the dominant blue-greens A. scheremetievi; A. circinalis, and C. naegelianum represented 89-96% of the total epilimnic plankton, which ranged from 5.9 to 34 mm^3 $liter^{-1}$.

Among the hypolimnic plankton, M. granulata showed quite a high biomass in late February (4.1 mm^3 $liter^{-1}$) and a smaller, but notable, concentration in mid-July (1.0 mm^3 $liter^{-1}$). On one survey date early in July the hypolimnic concentration of C. naegelianum was quite high (7.4 mm^3 $liter^{-1}$), but contributions from this species did not reach 1.0 mm^3 $liter^{-1}$ again until early October (1.7 mm^3 $liter^{-1}$). A. scheremetievi was not detected in high concentrations in the hypolimnion, except on one survey early in October (3.3 mm^3 $liter^{-1}$). Aggregations of fine mineral detritus were often abundant in the lower waters. Clumps of a narrow fiber (1.6-μ diam.) thought to be organic material (possibly silicon, p. 86) were also seen. Actinomycetes and the iron bacterium Leptothrix were observed occasionally.

1975--Spring and summer samples contained low concentrations of diatoms and the dinoflagellates Cryptomonas spp. and Ceratium hirundinella. Early in June the rotifer Polyarthra sp. became noticeable.

The Anabaena scheremetievi population was negligible early in June. By mid-July it had reached 3.5 mm^3 $liter^{-1}$, and a peak bloom of 8.7 was recorded late in August. The average biomass from July 29 through September 8 was 6.5 mm^3 $liter^{-1}$. By late fall it was well below 1.0 mm^3 $liter^{-1}$.

Coelosphaerium naegelianum was scarce compared to previous years, peaking at 1.4 mm^3 $liter^{-1}$ early in September. The chrysophyte Mallomonas sp. was a minor contributor to the plankton community in September. Cryptomonas ovata reached small bloom proportions (1.1 mm^3 $liter^{-1}$) in mid-October.

The hypolimnic plankton biomass was low throughout the sampling season. Anabaena and Coelosphaerium, dominant in the epilimnion, did not contribute significantly to the hypolimnion, although Coelosphaerium reached 1.1 mm^3 $liter^{-1}$ late in September. Aggregates of fine mineral detritus were very prevalent in the lower waters, accompanied in spring and early summer by high concentrations of an actinomycete and the iron bacteria Siderocapsa and Leptothrix.

Upper St. Regis Lake

Upper St. Regis Lake was viewed as a control lake which might show the conditions to be expected in Lower St. Regis Lake in the absence of pollution from the Paul Smith's College sewage treatment plant. For this reason its plankton community was of special interest.

Predominant Plankton--

Figures 28-29 illustrate the epilimnic biomass pattern for the predominent plankton species for 1972-1974. The chrysophyte Uroglenopsis americana and the colonial blue-green Anacystis incerta were the chief epilimnic phytoplankton in the spring/early summer and summer/fall, respectively. Dinobryon bavaricum (Chrysophyta) produced a significant bloom in the spring of 1973.

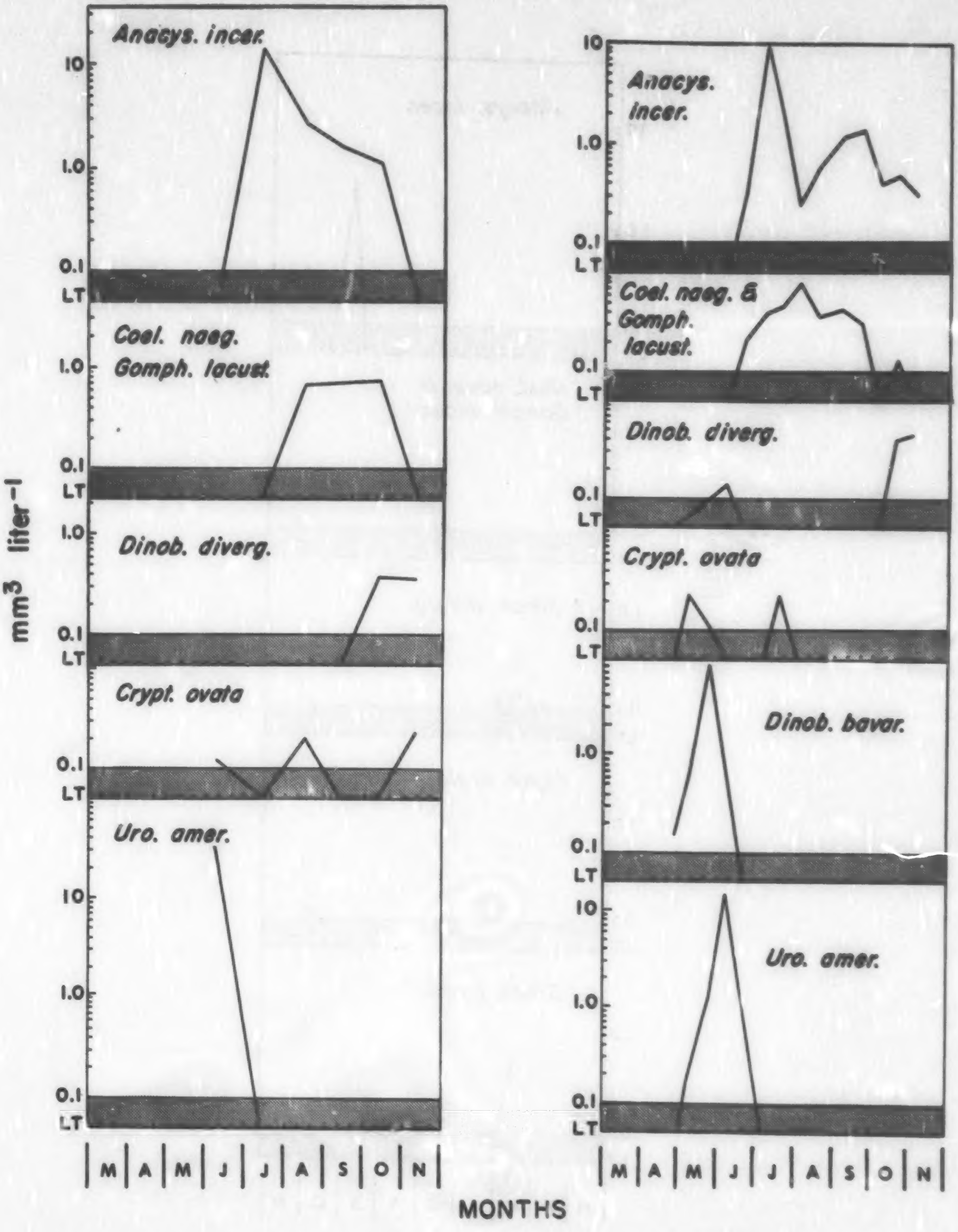

Fig. 28. Species biomass for Upper St. Regis Lake epilimnion, 1972 (left) - 1973 (right). LT = less than

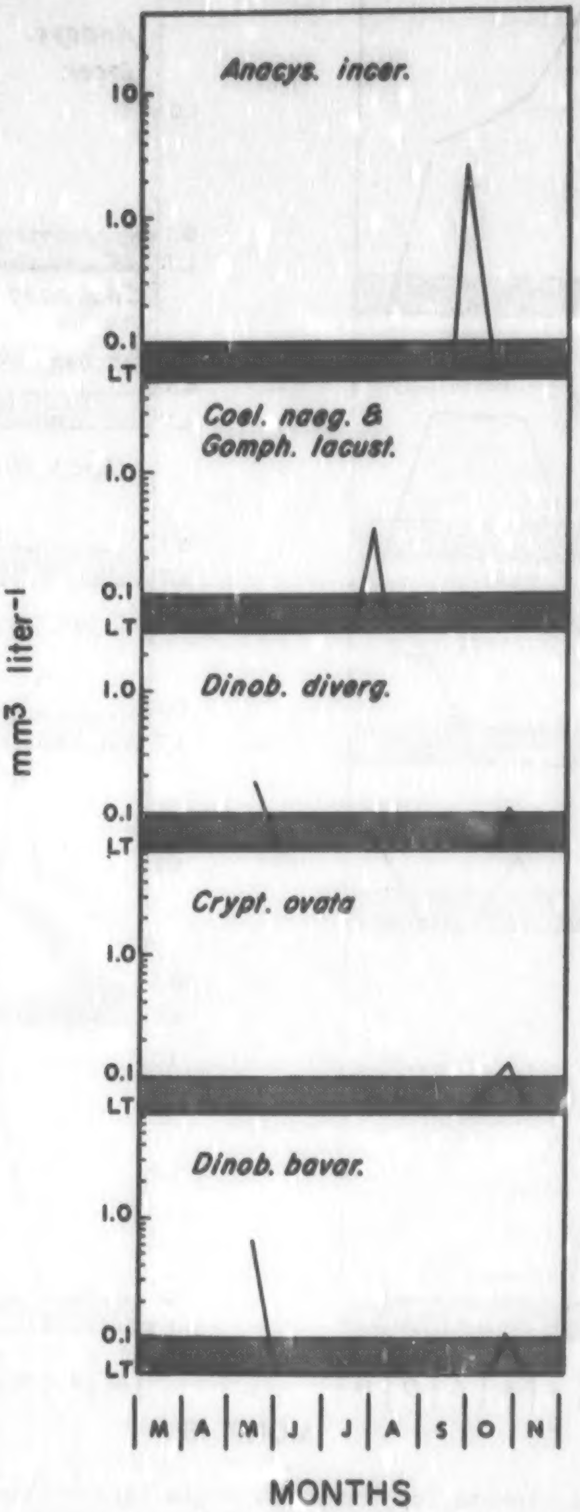

Fig. 29. Species biomass for Upper St. Regis Lake epilimnion, 1974.
LT = less than

The blue-green Coelosphaerium naegelianum, in addition to the species just mentioned, contributed most to the hypolimnic biomass during these years.

Figures 30-32 illustrate the total biomass of predominant plankton (epilimnion and hypolimnion curves) for 1972-1974. The major observations for each year can be summarized as follows:

1972--In early June macroscopic white specks were visible in the epilimnic sample. They consisted of Anabaena flos-aquae and large ciliates. On this survey there was also a bloom of the large colonial chrysophyte Uroglenopsis americana. Due to large colony size and scarcity of colonies, the biomass estimates for Uroglenopsis were not considered reliable, with the exception of this June epilimnion sample from Upper St. Regis Lake. The species volume derived from this sample (32 mm^3 liter^{-1}) was considered representative because the colony concentration was sufficiently high to allow a count of 70 colonies within a concentration of 10 ml of sample.

By mid-July the biomass of Anacystis incerta (Cyanophyta) was very high (14 mm^3 liter^{-1}). This remained the most important species through mid-October, accounting for 50-100% of the total epilimnic plankton biomass, which ranged from 1.9-14 mm^3 liter^{-1}.

The dinoflagellates Cryptomonas erosa and C. ovata were found in low concentrations throughout the sampling season. The blue-greens Coelosphaerium naegelianum (summer) and Gomphosphaeria lacustris (summer/fall) contributed a small biomass to the epilimnion, as did Dinobryon divergens (fall).

By early June the lower waters contained a high concentration of U. americana (6.5 mm^3 liter^{-1}). In mid-July C. naegelianum was recorded at 5.9 mm^3 liter^{-1} in the hypolimnion. Chrysosphaerella longispina was also apparent at that time. In August-October A. incerta concentrations for the most part peaked over 1.0 mm^3 liter^{-1}. Species contributing lesser amounts to the hypolimnion from late summer through late fall were G. lacustris, D. divergens, and Cryptomonas spp.

1973--In late May Dinobryon bavaricum exhibited a bloom of 8.8 mm^3 liter^{-1}. During that survey Uroglenopsis americana reached 1.2 mm^3 liter^{-1}, and by early June it was estimated at 15 mm^3 liter^{-1}. By late June its biomass was down to 1.4 mm^3 liter^{-1}. However, the Uroglenopsis counts were too low to produce a reliable biomass estimate. Synura was found in low concentrations in mid-July.

The peak biomass for Anacystis incerta was recorded early in July (9.0 mm^3 liter^{-1}). This species exceeded 1.0 mm^3 liter^{-1} in mid-July and again in September but otherwise produced only a small biomass from late June through the sampling season.

Cryptomonas ovata was found in low concentrations (above 0.10 mm^3 liter^{-1}) from spring through midsummer, as was Gomphosphaeria lacustris (summer and fall) and Dinobryon divergens (late fall).

In the spring and early summer the chief contributors to the hypolimnic

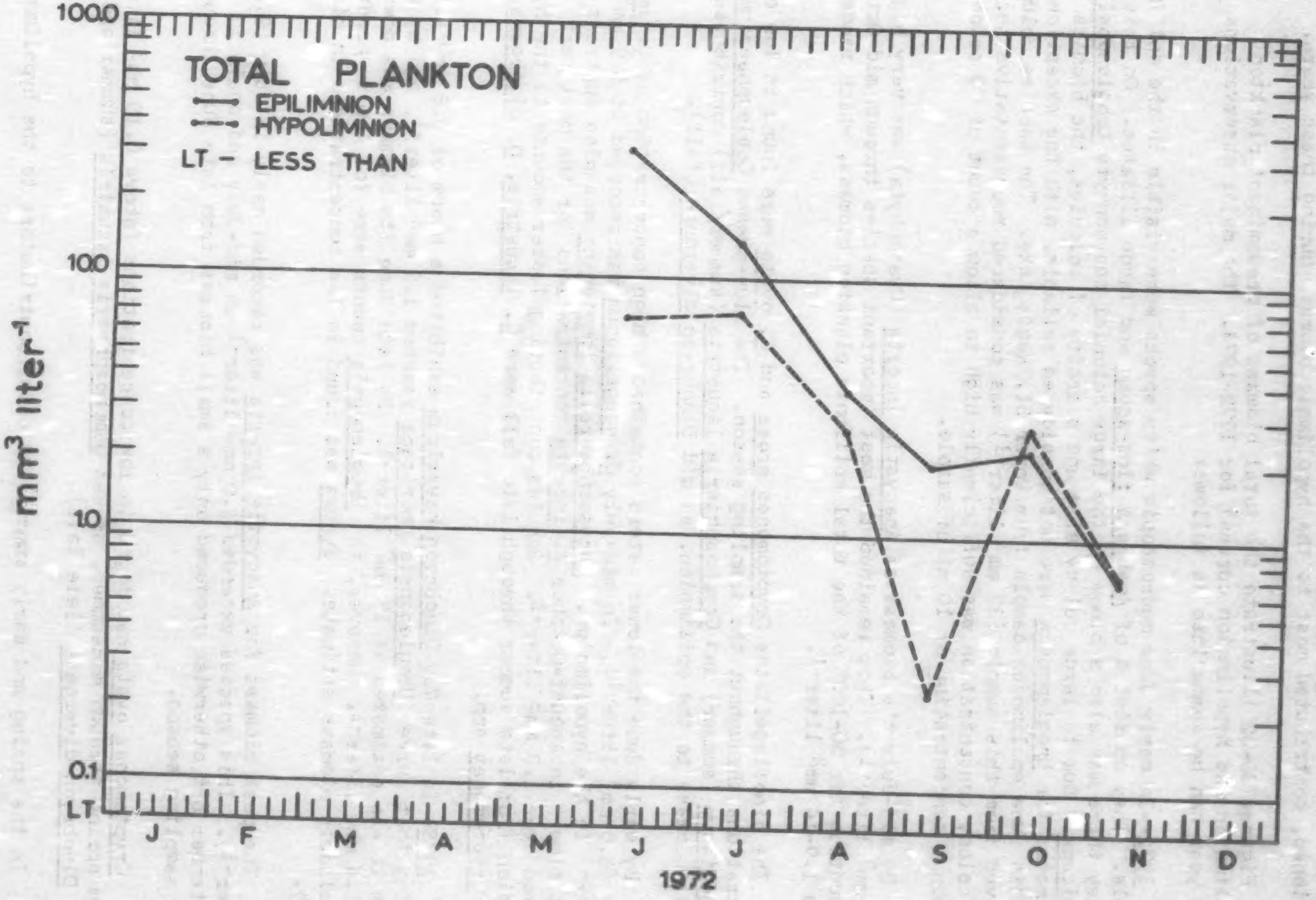

Fig. 30. Total plankton biomass for Upper St. Regis Lake, 1972.

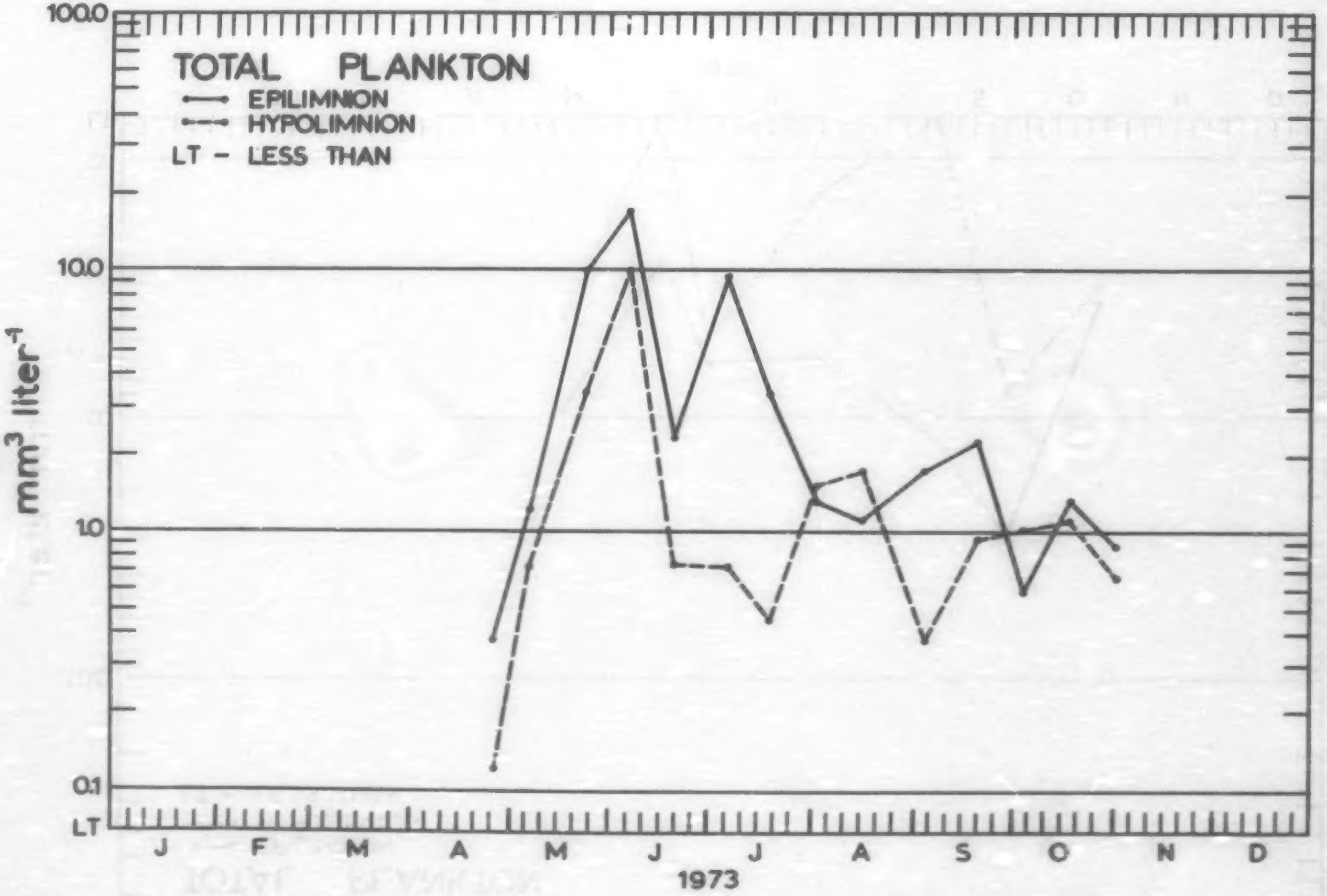

Fig. 31. Total plankton biomass for Upper St. Regis Lake, 1973.

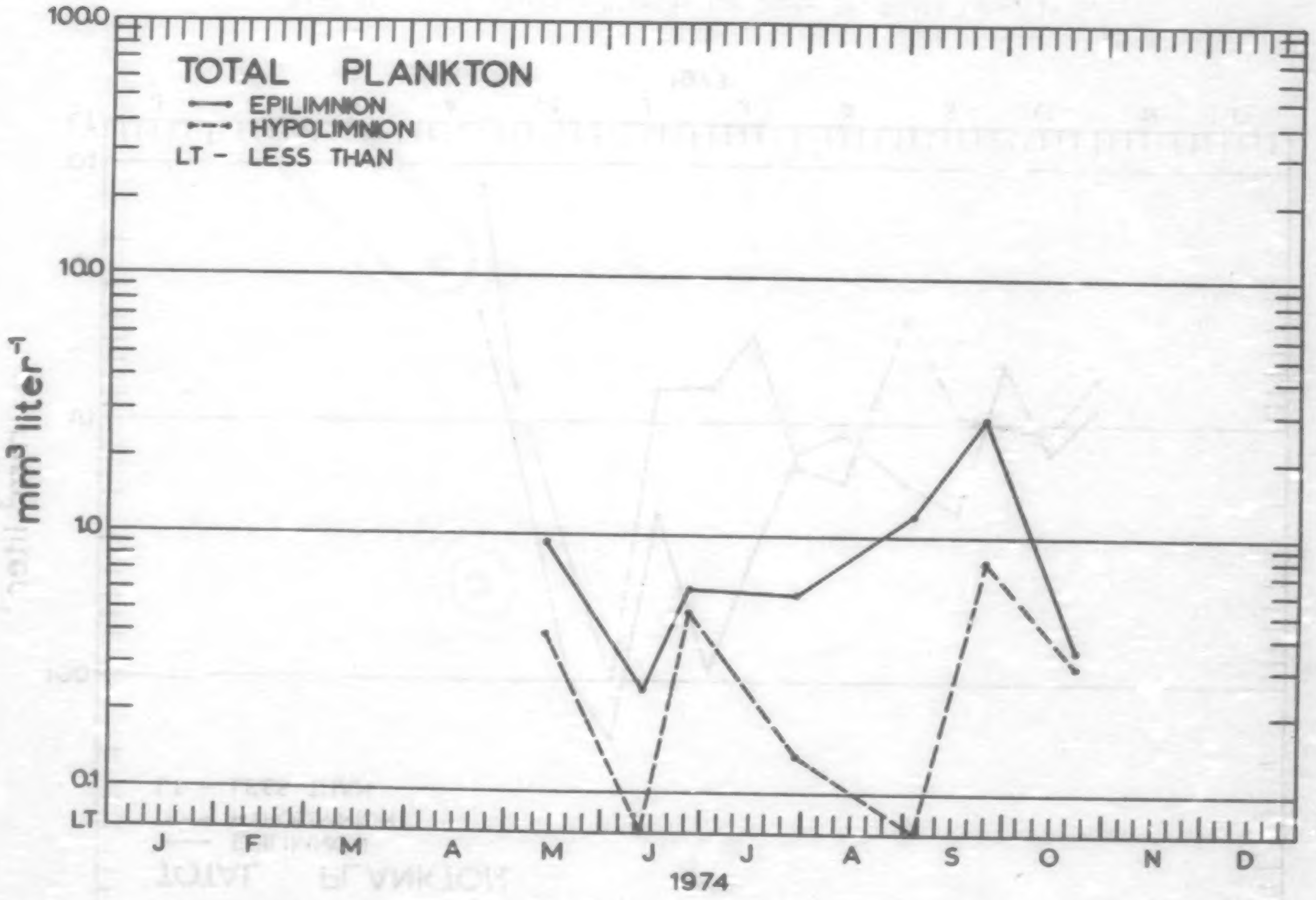

Fig. 32. Total plankton biomass for Upper St. Regis Lake, 1974.

biomass were D. bavaricum (peaks of 2.2 and 3.3 mm^3 liter^{-1}) and U. americana (peak of 6.0 mm^3 liter^{-1}). In June Synura spp. were noticeable in the lower waters.

A. incerta was found in low concentrations in the hypolimnion from mid-July to mid-October, peaking at 1.0 mm^3 liter^{-1} early in October. G. lacustris was apparent in the latter half of the summer; D. divergens, in the latter half of the fall.

The sulfur bacterium Beggiatoa, as well as other filamentous bacteria and an unusual filamentous type of detritus (believed to be organic material, possibly silicon, p. 86) were occasionally noticed in the hypolimnic samples.

1974--The high biomass recorded in spring to midsummer of the previous two years was absent in 1974. No Uroglenopsis americana bloom was seen in May or June. Dinobryon spp. values were low, and Anacystis incerta reached bloom conditions only late in September (2.6 mm^3 liter^{-1}). Aside from this bloom, the plankton biomass of the epilimnion was small. The following species appeared sporadically in low concentrations: Dinobryon bavaricum (mid-May), Cyclotella sp. (late June), Gomphosphaeria lacustris (late July), and Tabellaria fenestrata and Peridinium cinctum (early September). The detritus concentration was high in many samples from the surface and epilimnion, especially that of the unusual filamentous detritus seen in the hypolimnion the previous year. The iron bacterium Siderocapsa was occasionally noted.

The hypolimnic plankton biomass was likewise low, punctuated by low concentrations of Siderocapsa in spring and fall and of the diatom Melosira granulata in late September. Most samples contained an abundance of mineral detritus aggregations. The unusual filamentous detritus observed the previous year was present in 1974 as well, occasionally in high concentrations.

Spitfire Lake

Spitfire Lake is of interest primarily because it lies immediately above Lower St. Regis Lake. Its plankton community is an indicator of the quality of water the lower lake receives from the upper lakes. Due to the shallowness of Spitfire Lake the lower waters were not sampled.

Predominant Plankton--

Figures 33-34 illustrate the epilimnic biomass pattern for the predominant plankton species during 1973-1974. The chrysophytes Uroglenopsis americana (1973), Dinobryon bavaricum, and Melosira granulata were the chief phytoplankton in the spring and early summer. The blue-green alga Anacystis incerta was important during the summer and fall of 1973. M. granulata and Dinobryon divergens exhibited small blooms in the fall.

Figures 35-36 illustrate the total biomass of predominant plankton in the epilimnion for 1973-1974. The major observations for each year can be summarized as follows:

1973--During the spring and early summer, the prevailing species were the four chrysophytes Melosira granulata, Dinobryon bavaricum, Uroglenopsis americana,

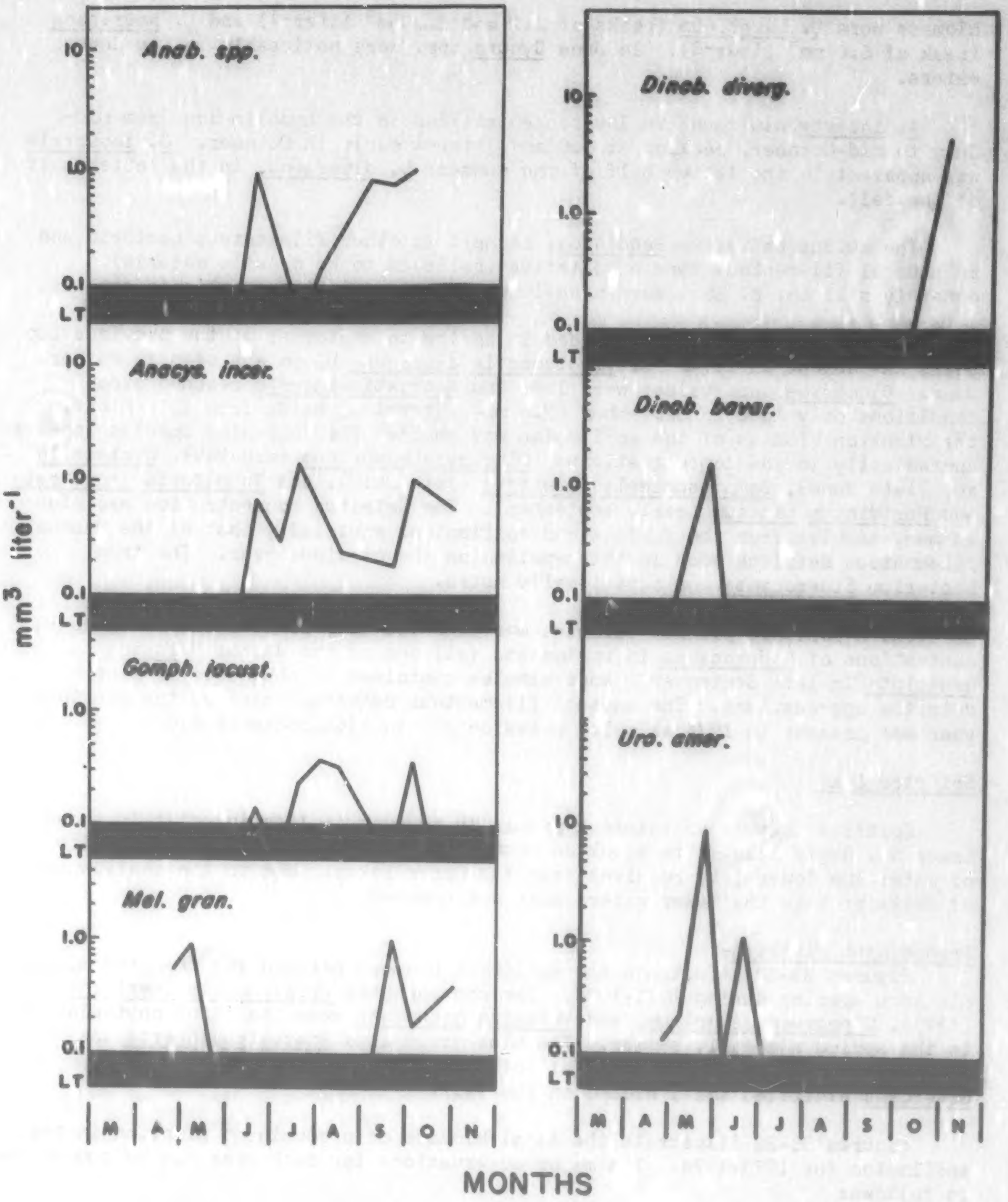

Fig. 33. Species biomass for Spitfire Lake epilimnion, 1973.
LT = less than

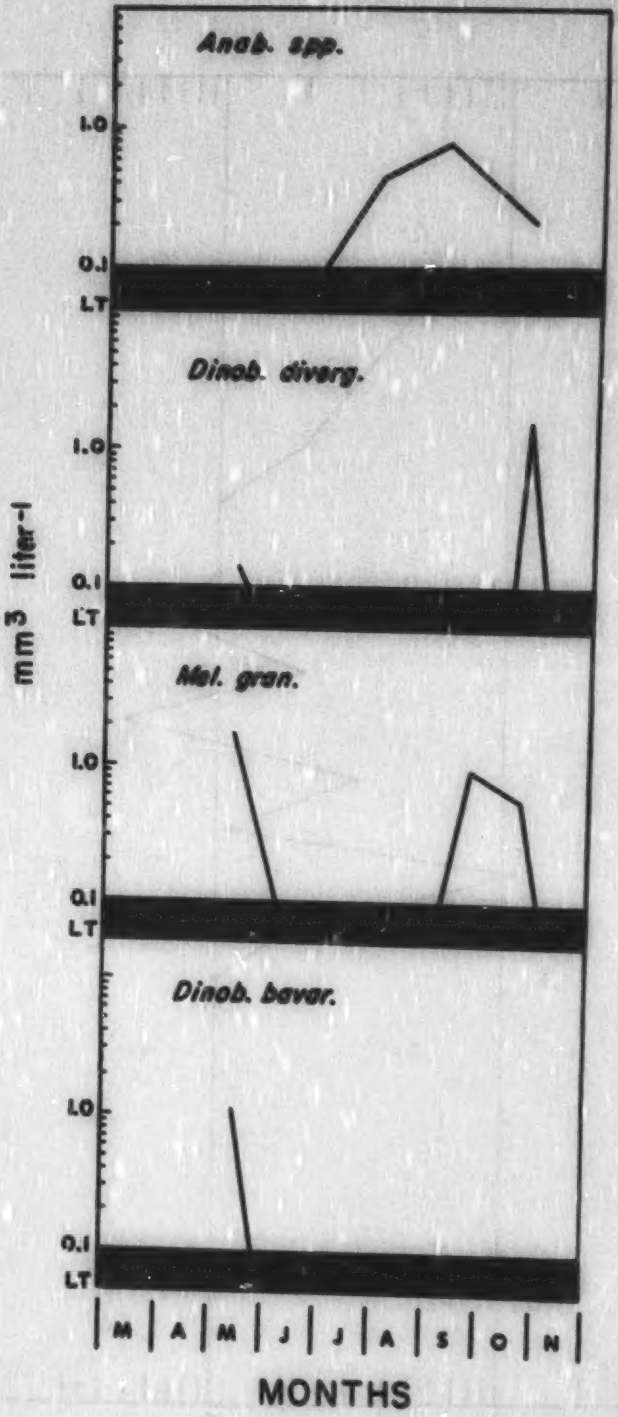

Fig. 34. Species biomass for Spitfire Lake epilimnion, 1974.
LT = less than

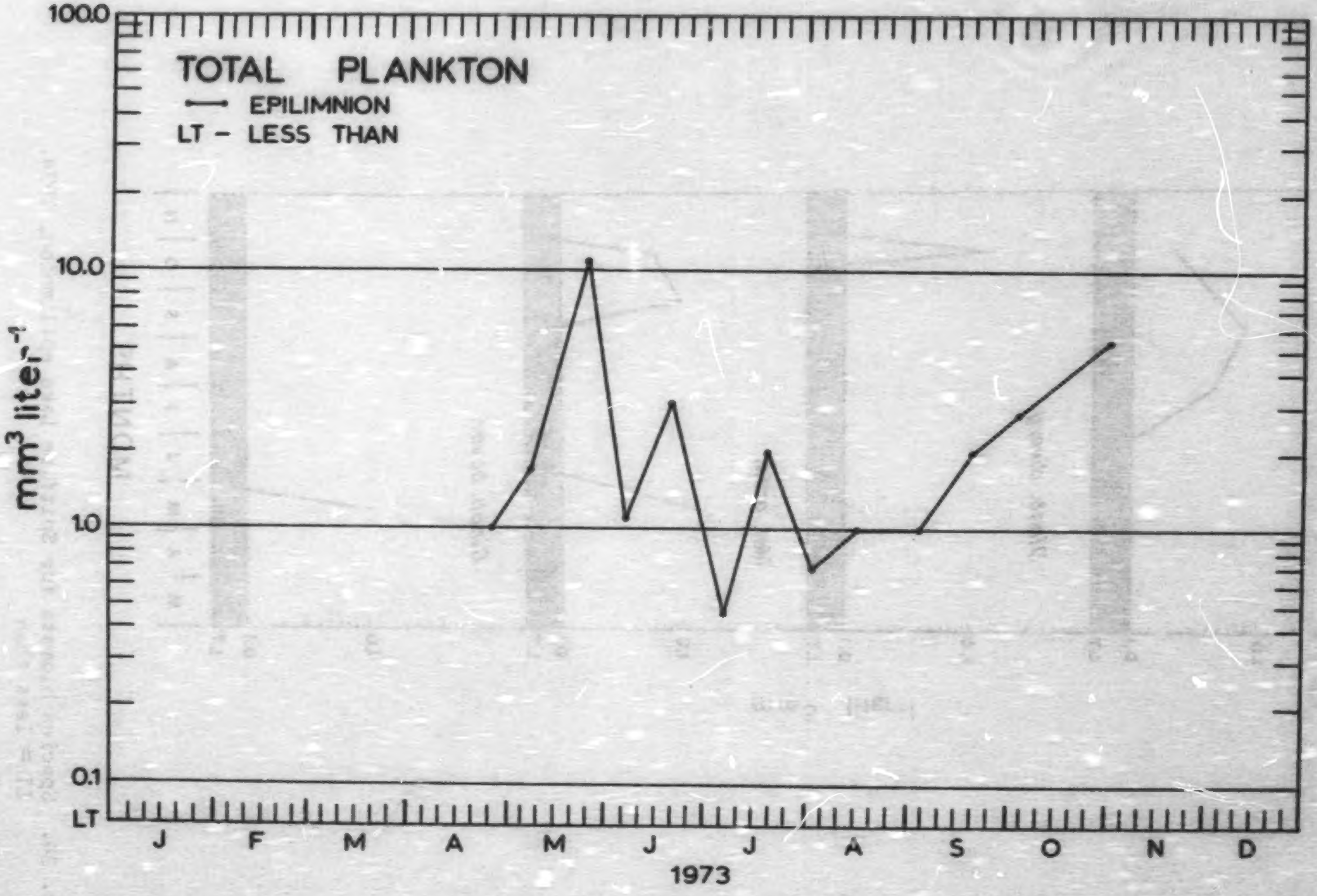

Fig. 35. Total plankton biomass for Spitfire Lake, 1973.

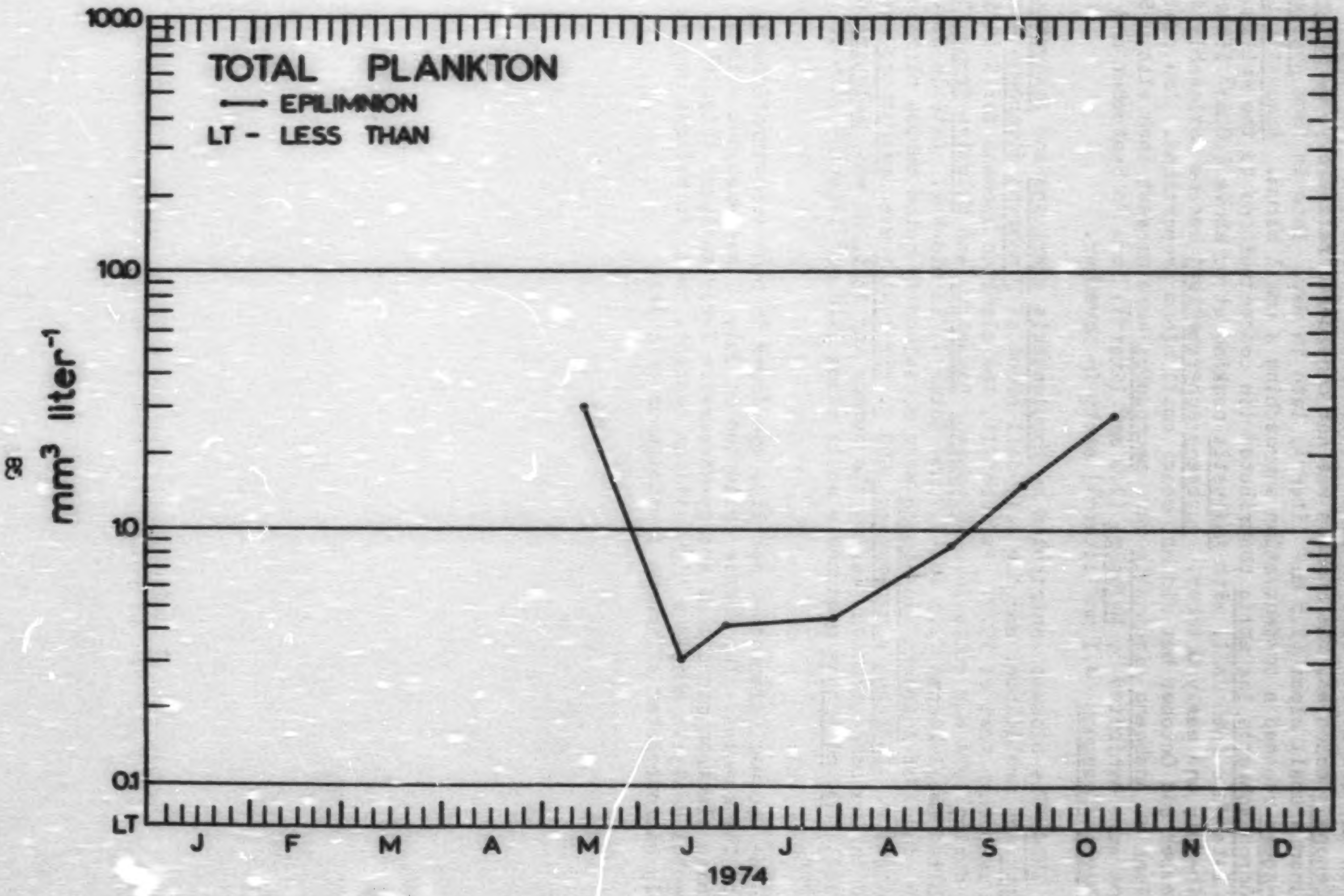

Fig. 36. Total plankton biomass for Spitfire Lake, 1974.

and Asterionella formosa. *Uroglenopsis* estimates peaked at 9.5 mm^3 liter^{-1} late in May and at 1.1 late in June. (Due to the scarcity of the large *Uroglenopsis* colonies, the biomass was not considered reliable.) *D. bavaricum* attained a small bloom (1.5 mm^3 liter^{-1}) late in May. Late in June *Anabaena flos-aquae* reached a concentration approaching a small bloom. *Anacystis incerta* and *Gomphosphaeria lacustris* contributed low concentrations to the epilimnion from late June into fall, with *Anacystis* peaking at or above 1.0 mm^3 liter^{-1} in mid-July and early October. *Anabaena scheremetievi* became noticeable during September and October but did not reach small bloom proportions. Low concentrations of *Anabaena circinalis* var. *macrospora* were present then also. Small blooms were exhibited by *Melosira* (1.0 mm^3 liter^{-1}) late in September and by *Dinobryon divergens* (4.1 mm^3 liter^{-1}) early in November.

1974--The biomass contributed by *Uroglenopsis americana* and *Anacystis incerta* was negligible, and the late fall bloom of *Dinobryon divergens* was much less than that of 1973. As a result, the plankton biomass for Spitfire Lake during 1974 was quite low. *Dinobryon bavaricum* and *Melosira granulata* exhibited small blooms (1.1 and 1.7 mm^3 liter^{-1}) in mid-May. Late in June large clumps of *Anabaena flos-aquae* were occasionally noted during microscopic examination. *Anabaena scheremetievi* and *A. circinalis* var. *macrospora* were found in low concentrations during the summer and fall, as was *Melosira* during the fall. *D. divergens* produced a small bloom (1.6 mm^3 liter^{-1}) late in October.

The unusual filamentous detritus was found in high concentrations in a few of the samples. The sample collected on July 30 was examined with a scanning electron microscope energy-dispersive X-ray analyzer (Fig. 37). Since elemental analysis showed a high silicon content, these formations may be partly disintegrated siliceous frustules or spicules.

Fig. 37. Unidentified particles (possibly silicon) from Spitfire Lake. Scanning electron microscope energy dispersive X-ray analyzer photomicrograph of sample collected July 30, 1974. Scale marker = 1.0 μ.

SECTION 9

LAKE CHEMICAL INPUTS AND CHEMICAL BALANCES

CHARACTERISTICS OF TRIBUTARIES

The chemical characteristics of the three gaged tributaries are summarized on Tables 16-18. Of the three, Black Pond outlet must be considered most characteristic for the basin, as it covers a large forested watershed without population. The retention time of Black Pond is minimal, and the outlet is rapidly moving and contains little humic matter. Analytical results for this creek correlate well with analyses of undisturbed groundwater near Paul Smith's College in the area now used for recharge. Although Black Pond drains not into the main basin of Lower St. Regis Lake but into the outlet and its contribution was not applied to the lake, the analytical log mean values were used to estimate inputs to the lake from ungaged natural sources. (In establishing nutrient balances, flow from Black Pond was deducted from St. Regis River flow to obtain outputs from the main basin of the lake.)

Easy Street Creek is a major direct tributary to the lake, but its electrolyte content is about 50% higher than that of the other gaged tributaries. This concerns the soluble major ions and is reflected in a higher conductivity. This effect can be assumed to be due to septic tank leachate from the "suburbs" of Paul Smiths, which are located in this watershed. Inputs from Easy Street Creek are shown in the nutrient balances.

Spitfire Creek is a very minor tributary emanating from a swampy area. When flow is low, the tributary forms an almost stagnant channel of strongly humic water. While the electrolyte content is normal, nutrients are often high and may reflect metabolism of the swampy area with periodic nutrient storage and release. Peaty substances are clearly evident in the analytical results for humic matter. Spitfire Creek may not reflect adequately the inputs for any major area in the watershed and was therefore ignored.

The input from the upper lakes was calculated using Spitfire Lake analytical results. Swampy areas in the watershed are not rare but discharge mainly into the upper lakes. A major wetland area, together with an open channel, connects Spitfire and Lower St. Regis lakes. Spitfire Lake water reaches the lower lake mainly via the open channel, but a rocking motion of the channel water occurs and can be attributed to slight lake level changes at both ends of the channel caused by wind. The wetlands will periodically contribute nutrients as rainfall and groundwater flow push water from the marsh into the open channel and as nutrients from these sources are taken up and released by the marsh vegetation.

Table 16. FLOWS AND CHEMICAL CONCENTRATIONS; LOGARITHMIC MEANS, RANGES, AND PROBABILITIES OF OCCURRENCE; BLACK POND OUTLET

Paramater	Min.	P=.02500	P=.10000	P=.25000	Lg mean	P=.75000	P=.90000	P=.97500	Max.	S/base 10 lg	N
Discharge	.020	.024	.043	.070	.120	.206	.338	.610	.300	.339000	23
Conductivity	38.800	35.865	40.629	45.129	50.531	56.580	62.847	71.195	63.400	.071578	23
Alkalinity	.074	.080	.111	.145	.194	.259	.340	.469	.700	.182725	21
Na +	.070	.014	.026	.039	.060	.093	.142	.252	.250	.263000	9
K +	.008	.004	.007	.010	.015	.022	.032	.055	.046	.242000	9
Mg ++	.050	.037	.051	.065	.083	.105	.134	.186	.110	.149000	9
Ca total	.070	.073	.108	.145	.194	.261	.348	.515	.320	.179000	9
Fe total	1.400	.228	.522	1.051	2.228	4.727	9.505	21.784	16.000	.476000	23
Mn total	.360	.032	.183	.403	.735	1.340	2.947	17.123	2.000	.317000	4
Cl^-	.074	.005	.014	.028	.056	.113	.225	.575	.400	.428000	9
SO_4=	.130	.116	.136	.151	.168	.187	.208	.244	.190	.063000	7
N (NO_3+NO_2)	100.000	16.858	59.982	153.686	397.192	1026.518	2630.136	9358.268	8000.000	.580000	9
N (NH_4)	20.000	13.982	23.395	35.930	56.885	90.061	138.317	231.433	360.000	.290000	20
N organic	50.000	8.039	35.471	122.822	465.586	1764.910	6111.132	26963.481	3200.000	.842000	21
P react.	2.000	1.980	3.450	5.514	9.141	15.154	24.222	42.203	35.000	.320260	24
P total sol.	4.000	1.799	3.901	7.471	15.021	30.199	57.835	125.401	66.000	.441700	22
P total part.	.800	.432	1.199	2.799	6.925	17.136	40.007	111.128	61.000	.571184	19
Si react.	20.000	16.853	35.542	61.799	108.000	118.741	328.173	692.118	270.000	.341000	9
C org. sol.	24.000	17.100	21.399	24.691	28.219	32.250	37.211	46.567	37.000	.078244	6
Humic matter	1.000	.749	1.027	1.327	1.739	2.278	2.943	4.037	3.000	.169308	15

Units:
Discharge in m^3 sec^{-1}; conductivity in µS cm^{-1}; total alkalinity, Na, K, Mg, Ca, Cl, SO_4 in meq $liter^{-1}$; Fe, Mn, Si in µg-at $liter^{-1}$; N, P in µg $liter^{-1}$; C, humic matter in mg $liter^{-1}$

Abbreviations:

Min. = minimum
P = probability
Lg = logarithm
Max. = maximum
S/base 10 lg = standard deviation as $\log_{10}$
N = number of observations
Chemical symbols: see List of Abbreviations and Symbols (p. ix)

Table 17. FLOWS AND CHEMICAL CONCENTRATIONS; LOGARITHMIC MEANS, RANGES, AND PROBABILITIES OF OCCURRENCE; EASY STREET CREEK

Parameter	Min.	P=.02500	P=.10000	P=.25000	Lg mean	P=.75000	P=.90000	P=.97500	Max.	S/base 10 lg	N
Discharge	.032	.024	.030	.036	.044	.054	.064	.080	.170	.124150	58
Conductivity	52.200	55.758	59.509	62.983	67.019	71.314	75.477	80.555	81.500	.039703	49
Alkalinity	.056	.123	.176	.241	.339	.478	.654	.937	1.100	.219700	52
Na +	.056	.065	.078	.091	.107	.127	.149	.178	.260	.108300	42
K +	.008	.007	.010	.013	.017	.024	.031	.043	.150	.196000	42
Mg ++	.008	.044	.063	.087	.123	.175	.240	.347	.210	.221965	40
Ca total	.130	.151	.180	.209	.246	.289	.336	.400	.360	.104490	42
Fe total	.000	2.266	3.403	4.856	7.173	10.596	15.118	22.690	32.000	.249700	59
Mn total	.073	.090	.163	.267	.455	.775	1.272	2.295	1.600	.336800	22
Cl^-	.028	.027	.043	.062	.094	.142	.207	.321	.340	.263300	38
SO_4=	.021	.031	.049	.074	.115	.178	.267	.427	1.500	.280288	35
N (NO_3+NO_2)	100.000	69.312	146.941	281.278	570.953	1158.948	2218.483	4703.194	11000.000	.451448	38
N (NH_4)	20.000	7.646	15.528	28.720	56.234	110.105	203.644	413.603	700.000	.429000	43
N organic	1.000	13.837	45.305	127.013	392.103	1210.466	3393.518	11111.014	8700.000	.720000	45
P react.	1.000	1.398	2.588	4.406	7.870	14.060	23.939	44.317	37.000	.370000	38
P total sol.	1.000	3.253	6.561	12.017	23.227	44.897	82.224	165.861	100.000	.420000	36
P total part.	1.000	.922	1.973	3.828	7.905	16.326	31.669	67.778	54.000	.453500	48
Si react.	28.000	64.214	92.463	126.475	177.787	249.918	341.848	492.233	300.000	.216800	33
C org. sol.	1.000	2.700	5.705	10.851	21.827	43.907	83.508	176.480	100.000	.444950	33
C part.	.500	.204	.365	.602	1.036	1.783	2.939	5.264	5.000	.345700	32
Humic matter	3.000	2.141	2.788	3.430	4.256	5.280	6.497	8.461	8.000	.133890	12

Units:

Discharge in m^3 sec^{-1}; conductivity in µS cm^{-1}; total alkalinity, Na, K, Mg, Ca, Cl, SO_4 in meq $liter^{-1}$; Fe, Mn, Si in µg-at $liter^{-1}$; N, P in µg $liter^{-1}$; C, humic matter in mg $liter^{-1}$

Abbreviations:

Min. = minimum
P = probability
Lg = logarithm
Max. = maximum
S/base 10 lg = standard deviation as $\log_{10}$
N = number of observations
Chemical symbols: see List of Abbreviations and Symbols (p. ix)

Table 18. FLOWS AND CHEMICAL CONCENTRATIONS; LOGARITHMIC MEANS, RANGES, AND PROBABILITIES OF OCCURRENCE; SPITFIRE CREEK

Parameter	Min.	P=.02500	P=.10000	P=.25000	Lg mean	P=.75000	P=90000	P=97500	Max.	S/base 10 lg	N
Discharge	.001	.000	.001	.002	.006	.023	.071	.266	7.000	.802000	49
Conductivity	33.000	35.418	39.851	44.167	49.431	55.323	61.314	68.989	67.000	.071990	50
Alkalinity	.020	.019	.038	.067	.126	.237	.421	.819	1.000	.403000	44
Na +	.022	.012	.022	.038	.068	.121	.205	.379	3.000	.367980	37
K +	.003	.004	.006	.009	.013	.018	.025	.036	.031	.223760	36
Mg ++	.008	.018	.027	.038	.055	.080	.114	.169	.180	.239600	37
Ca total	.025	.039	.058	.081	.117	.168	.236	.354	.250	.229181	20
Fe total	.280	1.420	2.539	4.220	7.367	12.861	21.378	38.235	17.000	.356476	55
Mn total	.055	.113	.181	.268	.407	.620	.918	1.469	1.300	.265000	20
Cl^-	.014	.010	.017	.027	.046	.077	.124	.216	.760	.331100	35
SO_4=	.083	.068	.096	.128	.176	.241	.323	.454	.830	.201869	32
N (NO_3+NO_2)	5.100	17.082	44.855	103.742	259.418	648.703	1500.340	3939.639	8000.000	.585300	44
N (NH_4)	20.000	6.124	15.869	36.327	89.877	222.369	509.027	1319.103	30150.000	.578733	46
N organic	5.000	65.637	148.746	303.150	660.693	1439.936	2934.641	6650.459	4100.000	.497800	47
P react.	1.000	3.246	5.706	9.292	15.812	26.908	43.816	77.034	46.000	.339000	38
P total sol.	5.000	8.537	14.445	22.710	37.154	60.782	95.561	161.699	280.000	.313489	34
P total part.	1.000	.593	1.615	3.841	9.880	25.416	60.430	164.490	280.000	.602650	39
Si react.	10.000	7.868	18.087	36.857	79.781	172.694	351.921	808.925	1200.000	.491000	30
C org. sol.	13.000	16.714	22.076	27.924	35.975	46.347	58.625	77.432	72.000	.160[illegible]92	24
C part.	.500	.172	.332	.582	1.074	1.981	3.479	6.693	11.700	.390000	34
Humic matter	3.000	2.692	5.378	9.494	17.374	31.794	56.133	112.138	227.000	.379850	17

Units:

Discharge in $m^3 sec^{-1}$; conductivity in $\mu S cm^{-1}$; total alkalinity, Na, K, Mg, Ca, Cl, SO_4 in meq $liter^{-1}$; Fe, Mn, Si in µg-at $liter^{-1}$; N, P in µg $liter^{-1}$; C, humic matter in mg $liter^{-1}$

Abbreviations:

Min. = minimum
P = probability
Lg = logarithm
Max. = maximum
S/base 10 lg = standard deviation as log_{10}
N = number of observations
Chemical symbols: see List of Abbreviations and Symbols (p. ix)

A lognormal distribution of concentration values was confirmed in the case of phosphorus, and it was inferred for other parameters from previous observations elsewhere (e.g., Fuhs, 1972; Fuhs and Allen, 1975). Regressions of phosphate concentrations on flow for Easy Street Creek did not produce significant correlations, and the log mean values were used to calculate inputs. To assess inputs from the upper lakes, the arithmetic means of values from consecutive surveys bracketing each period were employed.

PHOSPHORUS BUDGET

An estimate of phosphorus inputs into Lower St. Regis Lake is shown in Table 19 and summarized in Table 20.

Table 20. SUMMARY OF PHOSPHORUS INPUTS AND LOSSES INTO LOWER ST. REGIS LAKE (kg)

Period	Precipitation	STP	Other inputs	Total	Sedimentation	Outflow	Outflow/ inputs
Nov 72-Apr 73	42	100	1004	1104	n.d.	1933	1.75
May 73-Oct 73	64	28	747	775	13	932	1.20
Nov 73-Apr 74	42	194	693	887	n.d.	554	0.62
May 74-Oct 74	86	(3)	654	657	432	930	1.42

STP = sewage treatment plant
n.d. = not determined

Phosphorus inputs from the sewage treatment plant amounted to 8-15% of the total inputs during the period when phosphate removal by iron precipitation was practiced during the summer. No phosphate removal occurred during winter. Areal loadings of phosphorus amounted to 1.0-1.3 g m^{-2} which confirms that this lake must still be considered eutrophic. Phosphate retention varied greatly with season, and a substantial excess of losses over inputs occurred over most periods, as has been observed by Larsen et al. (1975) in Lake Shagawa, Minnesota, during its recovery from phosphate eutrophication.

During the period of the study 1972-1974, the lake was subject to a phosphorus loading regime which is likely to produce deviations from the common predictions of eutrophy, chlorophyll density, and transparency as a function of phosphorus loadings. During winter sewage continued to enter, leading to high phosphate concentrations. During spring the nutrient was in part utilized by algae in a spring bloom of diatoms and flagellates but also was to some extent flushed from the lake during high spring flows. During summer sewage phosphorus inputs were reduced to 15-20% of their previous levels, causing a reduction and delay in the summer bloom. As the phosphorus budget indicates, this reduction was probably less than proportional to the reduction in inputs, as the blooms were fueled by phosphorus stored in the lake.

Table 19. PHOSPHORUS BUDGET, LOWER ST. REGIS LAKE
(kg P day^{-1})

Period ending	No. days	Prec.	Easy St. Creek	Inter-lake	Ungaged runoff	STP	Total input	Sedim.	St. Regis River
Oct 11 1972	11	0.13	0.13	1.13	0.26	0.33	1.98	7.72	3.00
Nov 9 1972	29	0.38	0.14	2.55	0.40	0.45	3.92	4.59	4.82
Jan 11 1973	63	0.26	0.13	3.21	0.63	0.49	4.72	n.d.	7.21
Feb 6 1973	26	0.16	0.12	2.03	0.57	0.71	3.59	n.d.	9.31
Apr 26 1973	79	0.22	0.15	6.24	1.18	0.57	8.36	n.d.	14.80
May 7 1973	11	0.26	0.16	2.72	0.90	0.29	4.33	n.d.	6.09
May 24 1973	17	0.54	0.16	7.54	1.09	0.27	9.60	0.49	10.41
Jun 6 1973	13	0.26	0.17	3.18	1.01	0.17	4.79	2.46	9.69
Jun 20 1973	14	0.54	0.16	4.55	0.82	0.21	6.28	0.21	6.86
Jul 6 1973	16	0.45	0.22	3.70	0.51	0.13	5.01	1.78	5.00
Jul 19 1973	13	0.26	0.15	1.39	0.46	0.13	2.39	0.00	2.31
Aug 2 1973	14	0.32	0.13	1.15	0.41	0.14	2.15	1.21	2.14
Aug 16 1973	14	0.23	0.12	2.18	0.32	0.19	3.04	0.00	3.71
Sep 4 1973	19	0.07	0.11	0.68	0.19	0.09	1.14	0.00	2.53
Sep 20 1973	16	0.62	0.19	1.82	0.37	0.22	3.22	0.00	4.13
Oct 4 1973	14	0.38	0.15	7.02	0.43	0.23	8.21	1.29	9.64
Oct 18 1973	14	0.24	0.12	0.35	0.45	0.26	1.42	0.86	1.64
Nov 1 1973	14	0.08	0.12	2.37	0.35	0.10	3.02	0.21	2.06
Feb 11 1974	92	0.26	0.14	3.20	0.51	0.77	4.88	n.d.	3.19
Mar 12 1974	29	0.14	0.12	3.30	0.78	1.28	5.62	n.d.	1.24
Mar 25 1974	13	0.37	0.11	4.47	0.59	1.60	7.14	n.d.	4.16
Apr 30 1974	36	0.31	0.18	1.66	1.22	1.62	4.99	n.d.	4.69
May 14 1974	14	0.48	0.24	7.04	1.76	0.22	9.74	0.24	12.71
Jun 13 1974	30	0.18	0.15	2.08	0.82	0.00	3.23	8.80	5.87
Jun 27 1974	14	0.32	0.15	1.13	0.64	0.00	2.24	2.14	1.93
Jul 30 1974	33	0.48	0.15	1.24	0.51	0.00	2.38	0.94	1.41
Sep 4 1974	36	0.33	0.10	1.47	0.51	0.00	2.41	1.33	4.67
Sep 26 1974	22	0.34	0.19	2.28	0.45	0.00	3.26	1.27	5.12
Oct 24 1974	28	0.15	0.12	4.70	0.35	0.00	5.32	3.79	7.58
Nov 6 1974	13	0.13	0.11	0.40	0.31	0.00	0.95	n.d.	1.31

Prec. = precipitation
STP = sewage treatment plant
Sedim. = sedimentation
n.d. = not determined

Other complicating factors were inputs in the form of plankton algae, which grow in Spitfire Lake and the connecting channel and are subject to sedimentation in the lower lake, and possible precipitation of phosphates with iron and manganese in the lower lake. For these reasons the relationship between phosphate concentrations and phytoplankton response is not likely to be typical, and indeed phytoplankton response was only half of the expected value.

NITROGEN BUDGET

Calculation of the nitrogen budget analogous to that of phosphorus showed inputs and outputs to be approximately balanced at 14,000 kg during the winter months of November 1973 through April 1974. Retention was 25% of 10,000 to 11,000 kg input during the summers (May-October) of 1973 and 1974. Sedimentation in these 6-month periods was 1,700 and 1,400 kg respectively. These losses may be due to accumulation of organic nitrogen in the sediment, or denitrification, or both.

SECTION 10

DISCUSSION

As a result of curtailment of sewage phosphorus inputs, Lower St. Regis Lake is recovering from severe eutrophication. Recovery became more pronounced since the time when 80% removal of sewage phosphorus during summer was replaced by 100% phosphorus removal year-round. Although the lake showed sufficient visible improvement during the first two years (1972, 1973) for the change to be noted by local residents, this improvement essentially consisted of a delay in the rising of the summer blue-green algal bloom to the surface. In summer 1975 the change was so dramatic that the lake no longer had objectionable qualities of any magnitude for more than 3 weeks, as opposed to all-summer nuisance conditions in the years preceding restoration. Since the sandbeds to which the sewage treatment effluent has been diverted are expected to retain phosphates completely for a great number of years, the lake could possibly recover to a state of eutrophy which may be less than the upper lakes. These lakes appear to receive septic tank leachate containing phosphates, whereas the lower lake has no such sources remaining (except 5 isolated cottages for temporary occupancy).

The eutrophic state of Lower St. Regis Lake is borne out by all measurements of epilimnic characteristics relevant in this respect (Table 21).

Table 21. MEASUREMENTS OF EUTROPHY, LOWER LAKE [a]

Constituent		Lower St. Regis Lake 1972	1973	1974
Chlorophyll a	(μg liter^{-1})	n.d.	8.2 ± 6.0	10.1 ± 7.3
Total phosphorus	(μg liter^{-1})	75 ± 26	77 ± 28	46 ± 32
Particulate phosphorus	(μg liter^{-1})	26 ± 10	29 ± 17	22 ± 20
Secchi disc transparency	(m)	1.56	1.72	1.74

n.d. = not determined

[a] Mean summer values.

The corresponding data for Upper St. Regis and Spitfire lakes are shown on Table 22.

Table 22. MEASUREMENTS OF EUTROPHY, UPPER LAKES [a]

Constituent	Upper St. Regis 1973	Upper St. Regis 1974	Spitfire 1973	Spitfire 1974
Chlorophyll a (μg liter^{-1})	1.6 ± 1.6	1.7 ± 0.8	1.7 ± 1.4	1.5 ± 0.5
Total phosphorus (μg liter^{-1})	44 ± 11	62 ± 33	62 ± 17	44 ± 28
Particulate phosphorus (μg liter^{-1})	12.5 ± 9	44 ± 30	19 ± 14	22 ± 18
Secchi disc transparency (m)	3.7	3.3	n.d.	n.d.

n.d. = not determined

[a] Mean summer values.

The eutrophic character is also evident from the epilimnic phosphate concentrations during spring overturn (Table 23).

Table 23. EPILIMNIC PHOSPHORUS DURING SPRING OVERTURN (μg P liter^{-1}), LOWER ST. REGIS LAKE

Year	Date	Soluble P	Particulate P	Total P
1972	May 9	42	28	70
1973	Apr 26	33	28	61
	May 7	60	14	74
1974	Mar 12	20	<1	21
	Apr 25	42	5	47
	Apr 30	35	17	52
	May 14	36	8.8	45

The apparent hypolimnic oxygen deficit in Lower St. Regis Lake calculated according to Hutchinson (1938) is around 0.030-0.045 mg $O_2 \cdot cm^{-2} \cdot day^{-1}$

and did not change materially over the study period. At the end of the season the hypolimnion is essentially depleted of oxygen. In lakes where this occurs, a true hypolimnic oxygen deficit can be calculated either by adding the oxygen demand of methane dissolved in the hypolimnion (Lasenby 1975) or by converting the oxygen deficit to a carbon dioxide basis and adding excess carbon dioxide derived from the anaerobic decomposition of organic matter (Ohle, 1952). Conversely, the excess carbon dioxide accumulation calculated according to Ohle can be converted to oxygen demand assuming a respiratory quotient of 0.85. We did not measure hypolimnic methane accumulation, so that the carbon dioxide method is the only one we can apply. If this is done it appears that the anaerobic processes in Lower St. Regis decreased during the study period indicating recovery from a severe to a lesser degree of eutrophy (Table 24).

Table 24. HYPOLIMNIC OXYGEN DEFICIT AND CARBON DIOXIDE ACCUMULATION IN LOWER ST. REGIS LAKE ($mg\ O_2 \cdot cm^{-2} \cdot day^{-1}$)

	Apparent oxygen deficit	Deficit calculated from excess carbon dioxide	True oxygen deficit
1971 May 1 - Aug 4	0.041	0.092	0.133
1972 May 1 - Jul 25	0.041	0.046	0.087
May 1 - Aug 15	0.029	0.024	0.053
1973 May 1 - Aug 2	0.042	0	0.042
May 1 - Aug 16	0.043	0	0.043
May 1 - Sep 4	0.033	0	0.033
1974 May 1 - Jul 20	0.028	0	0.028
May 1 - Sep 4	0.017	0.008	0.025
1975 May 1 - Jul 17	0.044	n.d.	n.d.

n.d. = not determined

The hypolimnic oxygen deficit for Upper St. Regis Lake cannot be calculated for lack of reliable bathymetric data. Spitfire Lake is too shallow to stratify.

Considering the fact that Lower St. Regis Lake is phosphate-limited, phosphorus loading data can be related to the response of the lake in terms of standing concentrations of phosphorus, chlorophyll, and transparency. As morphometric and hydrologic characteristics of the lake we use mean depth $\bar{z}$ = 5.6 m, mean hydraulic retention time τ_w = 0.215 yr (or hydraulic loading

$q_s = \bar{z} \cdot \tau_w^{-1} = 26.0$ m · yr^{-1}). Pre-study phosphorus loading is 1.16 g · m^{-2} · yr^{-1}; after point-source diversion the loading is 0.87 g · m^{-2} · yr^{-1}.

According to the empirical findings by Vollenweider (1968), both loading figures suggest the lake to be eutrophic (probability of transition to eutrophic at 0.14 mg P · m^{-2} · day^{-1} for $\bar{z} = 5.6$.) Introducing certain elements of the mixed reactor model (Vollenweider 1975, 1976), the predicted phosphorus concentration at spring overturn ($[P]^{sP}$) where L_p = areal phosphorus loading, would be

$$[P]^{sP} = L_p/\bar{z} \left(\frac{1 + \sqrt{\tau_w}}{\tau_w} \right)$$

or 30 μg liter^{-1} before and 22 μg liter^{-1} after point-source phosphorus control. The latter predicted value approaches the limit which separates eutrophy from mesotrophy (20 μg liter^{-1}). Measured values were often twice the predicted values (Table 23). If the predicted values are converted to chlorophyll, according to Sakamoto (1966), as

$$\log_{10} [\text{chl } a] = 1.45 \log_{10} [P]^{sP} - 1.14$$

the predicted values are 10 and 6.4 μg liter^{-1} respectively. This is close to the measured mean concentrations (Table 21). A similar discrepancy between phosphate and chlorophyll values was observed by Welch et al. (1973) in Lake Sammamish, Washington, and was explained in terms of unavailability of phosphate or iron. In the case of Lower St. Regis Lake, it is conceivable that easily available phosphorus from natural runoff is already largely exploited by the upper lakes and bog vegetation, and that the remainder is less readily available than the phosphates from the sewage treatment plant effluent. Likewise the contribution to Lower St. Regis Lake from direct runoff during the growing season may be less than the annual average. Available nutrients from base flow are likely to be retained in the wetland vegetation from where they are released only during fall and spring runoff.

Comparison with Lake Shagawa, Minnesota (Larsen et al., 1975), which is undergoing oligotrophication as a result of point-source phosphorus control, is equally instructive. That lake is undergoing phosphorus washout, but summer blooms still appear as the result of internal loading events, although the relative reduction of total phosphorus loading in Lake Shagawa is much more drastic (80%) than in St. Regis Lake.

Lower St. Regis Lake also has a more favorable morphology than Shagawa Lake. It is deeper and better stratified, and the near-circular basin shape reduces wind fetch and therefore mixed layer depth and the volume ratio of epilimnion to hypolimnion. This favors nutrient retention and delays thermocline erosion and internal loading events. (Lake Shagawa is 5 times larger and is unstratified except in "deep holes.")

Another factor favoring recovery of Lower St. Regis Lake is the abundance of iron in its waters, particularly the large amount which has been trapped over years of high productivity by sedimentation into the hypolimnion.

This iron will bind phosphorus until oxygen depletion reaches the upper layers of the hypolimnion. Any delay of hypolimnic oxygen depletion will delay phosphorus mobilization from the hypolimnion and therefore have a self-reinforcing effect. At fall overturn the iron will be reoxidized, and phosphate will be precipitated and deposited, available for summer algal growth only in the narrow littoral parts of the euphotic zone. Additional iron supply from sewage treatment in the summers of 1972 and 1973 undoubtedly has assisted in this regard. (Shagawa Lake is located in the iron ore district of Minnesota, yet no data on the iron cycle in that lake have become available.)

The causes for the internal loading events that lead to summer blooms in lakes even after reduction of phosphate inputs may differ from lake to lake. Thermocline erosion, which is a significant factor in Lake Mendota (Stauffer and Lee, 1973), is not measurably related to the explosive appearance of the *Anabaena* bloom in Lower St. Regis Lake.

It is interesting to note that in spite of the reduction of both bloom intensity and duration over the past 3 years, the hypolimnic oxygen depletion in the lake has not been reduced noticeably (Fig. 8). Observations on sediment cores show that the sediments are producing marsh gas in great amounts. Methane is a potentially very significant factor in the depletion of hypolimnic oxygen resources of lakes. The gas rises, in bubble or dissolved form, via currents to the oxygenated layer, where it is oxidized by bacteria. With the gas, phosphates released chemically are carried into the water column.

Akinetes of *Anabaena* were found at the surface of the sediment cores collected in winter and were easily brought to germination in the laboratory by illuminating the cores in their Plexiglas tubing and warming to room temperature. Akinetes could possibly be carried upward by gas bubbles or currents into the photic zone where they could germinate and develop a population, at first close to the thermocline, then rising by their gas vacuoles. Also, akinetes in the deeper littoral could germinate and greatly benefit from the infusion of hypolimnic nutrients when hypolimnic oxygen depletion progresses.

In experiments yet to be completed (they will be described in detail elsewhere), we have collected algae from Lower St. Regis Lake and processed them for cytochemical examination. Samples taken from the epilimnion in July 1974, before the onset of the *Anabaena* bloom, showed diatoms which were highly vacuolized and almost devoid of cytoplasm and reserve material. *Anabaena* filaments were present in small numbers but were in an extremely viable condition, as shown by their high protein and ribonucleic acid content and by the presence of polyphosphate granules (phosphate storage) and cyanophycin (nitrogen reserve). These cells were devoid of gas vacuoles. Their specific gravity is likely to be high, so that they are kept afloat by upward currents in the mixed layer (reducing loss rate by a high rate of multiplication), or develop a substantial population in the sediments in the littoral, or both. *Anabaena* filaments taken during bloom conditions were full of gas vacuoles and devoid of storage materials.

These observations and the evidence from light attenuation measurements of a rising of the bloom suggest that Anabaena develops in the lower epilimnion and subsequently rises to the surface when gas vacuoles have formed.

If the internal loading event leading to this bloom indeed is "driven" by methane forming in the sediments, an explanation would be found for the recurrence of the hypolimnic oxygen deficit even in the absence of a significant spring bloom (as in 1975) and for the recurrence of the algal bloom over the past 3 years, about 4 weeks after the effects of hypolimnic oxygen demand have reached both the photic zone and the thermocline at a depth of about 4-5 m. Reduced gassing during consolidation of the sediments could then be expected to result in the gradual disappearance of the bloom.

SECTION 11

THE FUTURE OF LOWER ST. REGIS LAKE

Lower St. Regis Lake will remain under scientific surveillance by the Environmental Health Center in cooperation with the State's regulatory agencies, with particular emphasis on lake water quality and containment of sewage phosphorus in the recharge beds.

As far as we can see, the future of the lake with regard to phosphorus loadings is secured by these measures, as well as by the prevailing patterns of land ownership and land use control. If the moderate eutrophy in the upper lakes becomes a reason for concern, reductions in phosphate inputs into that basin are possible. Since phosphate retention in the upper lakes is likely to be substantial, the lower lake can be expected to be less eutrophic than both upper lakes. In 1975, for the first time in the study period, it manifested a clear brown color during most of the summer season. Full recreational use of the lake is now possible throughout the season, although the pattern of ownership and the abundance of other recreational lakes in the area may not lead to a full realization of that potential.

While the lake is adjusting to its new condition, the sediments will undergo mineralization and consolidation, and favorable pH conditions will produce a more gyttja- rather than peatlike sediment. The relative reduction of blue-green algae, with a predominance of flagellates and some diatoms, may improve conditions for zooplankton and benthic invertebrate development. Fish populations resembling those in the upper lakes are likely to develop. Total fish productivity, however, may well remain below the levels in the upper lakes, due to somewhat lower primary productivity.

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INVENTIONS AND PUBLICATIONS

There have been no publications on this study to date except the following reports:

"Progress Report on Phosphate Removal at the Paul Smith's College Sewage Treatment Plant in Northern New York State" by T. J. Tofflemire, New York State Department of Environmental Conservation, Environmental Quality Research and Development Technical Paper No. 42, April 1975, 90 p.

Publications in scientific journals are contemplated and will include proper acknowledgments of grant support.

Specifications for a remote telemetering system for operation in remote areas were submitted to EPA earlier (Z. Kachemov, G. W. Fuhs and T. Moran, Memorandum Report dated June 22, 1973). The system was implemented in a one-channel version without unit conversion capability and tested with AM equipment. Even in remote areas, nighttime interference proved to be substantial, and conversion to FM operation proved necessary. At present, much of the system has been rebuilt with military specification components and tested at the St. Regis study site over an extreme temperature range. A modem has been purchased for direct interrogation of the master station from a computer station in the Albany, New York, laboratory. A new test series began in June 1976 using the FCC-approved Paul Smith's College master station and one remote station on nearby Upper Saranac Lake. Not only lake and stream levels but also productivity-related lake parameters will be measured, with future emphasis on developing more reliable sensors. Installation of a repeater station at one of several suitable locations would permit telemetry of valuable research and monitoring data at a modest cost from much of New York's Adirondack lake district.